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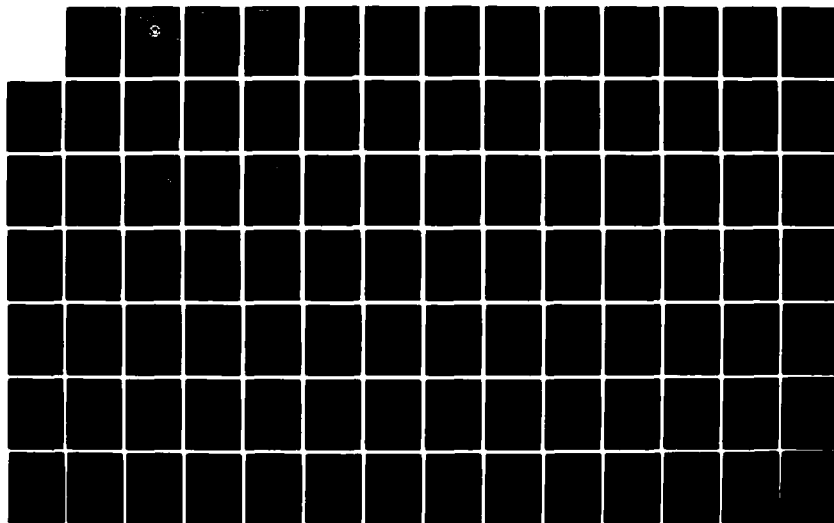
AUTOMATIC CONTROL AND DATA ACQUISITION SYSTEM FOR  
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## THESIS

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AUTOMATIC CONTROL AND DATA  
ACQUISITION SYSTEM FOR  
COMBUSTION LABORATORY APPLICATIONS

by

Bertel J. Hansen

October 1982

Thesis Advisor:

David W. Netzer

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Automatic Control and Data Acquisition System  
for Combustion Laboratory Applications

by

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Lieutenant, United States Navy  
B.S.E.E., North Carolina State University, 1975

Submitted in partial fulfillment of the  
requirements for the degrees of

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and

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# ABSTRACT

A modern computer based automatic data acquisition/control system was installed at the Department of Aeronautics' Combustion Laboratory. This system utilizes an HP-85 desktop computer as system controller for the HP-3054A data acquisition system. These major control applications include: (1) particle size determination by measurement of scattered laser light, (2) a vitiated air heater system, and (3) a solid fuel ramjet test unit. Details involving specific data acquisition/control techniques for these applications are discussed.

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# TABLE OF ABBREVIATIONS

HP-IB	Hewlett Packard Interface Bus
A/D	Analog to Digital
D/A	Digital to Analog
TTL	Transistor Transistor Logic
I/O	Input/Output
VFC	Vertical Forms Control
BBM	Break Before Make
EOL	End of Line
RAM	Random Access Memory
ROM	Read Only Memory
DAV	Data Available
EOC	End of Conversion

#### ACKNOWLEDGMENT

It is unlikely that this project could have been completed without the full support of my wife, Lois, and my family. Their tolerance and perseverance will be remembered always.

## I. INTRODUCTION

This thesis project was undertaken to develop and install a modern, computer based experiment control/data acquisition system at the Naval Postgraduate School Aeronautics Department, Combustion Laboratory. Previously, all laboratory experiments were manually controlled and all test data were reduced manually by hand with no real time data processing possible. Precise timing of test equipment and control features were difficult or impossible.

The introduction of the HP-3054A Automatic Data Acquisition system and the integration of all associated test equipment to a desktop computer have revolutionized current operations at the Combustion Laboratory.


Large quantities of high quality data can be acquired at high data rates and stored for future use or processed real time in closed loop feedback control circuits for precise process control and display.

Other electromechanical equipment such as Visicorders provide analog real time data and run in parallel with digital equipment but can be remotely controlled for precise timing of experiments.

Interactive programs on the HP-85 computer allow the experimenter to do preliminary calculations, initial experiment set-up, and to perform accurate process control of system

functions. On line data reduction and display of results is performed by the system CRT display, the 7225B Plotter, or the system printer.

Four basic experiments/experimental apparatuses are currently automated using the automatic data acquisition system; a light scattering experiment, a vitiated air heater, a solid fuel ramjet, and a turbojet combustor test rig. The first three applications are discussed in subsequent sections along with the measurement techniques used to implement the process.



## II. SYSTEM AND COMPONENT DESCRIPTIONS

To produce accurate test results involving high speed machinery and processes and simultaneously provide precise timing and control signals, a modern data acquisition system has been installed at the Combustion Laboratory at the Naval Postgraduate School.

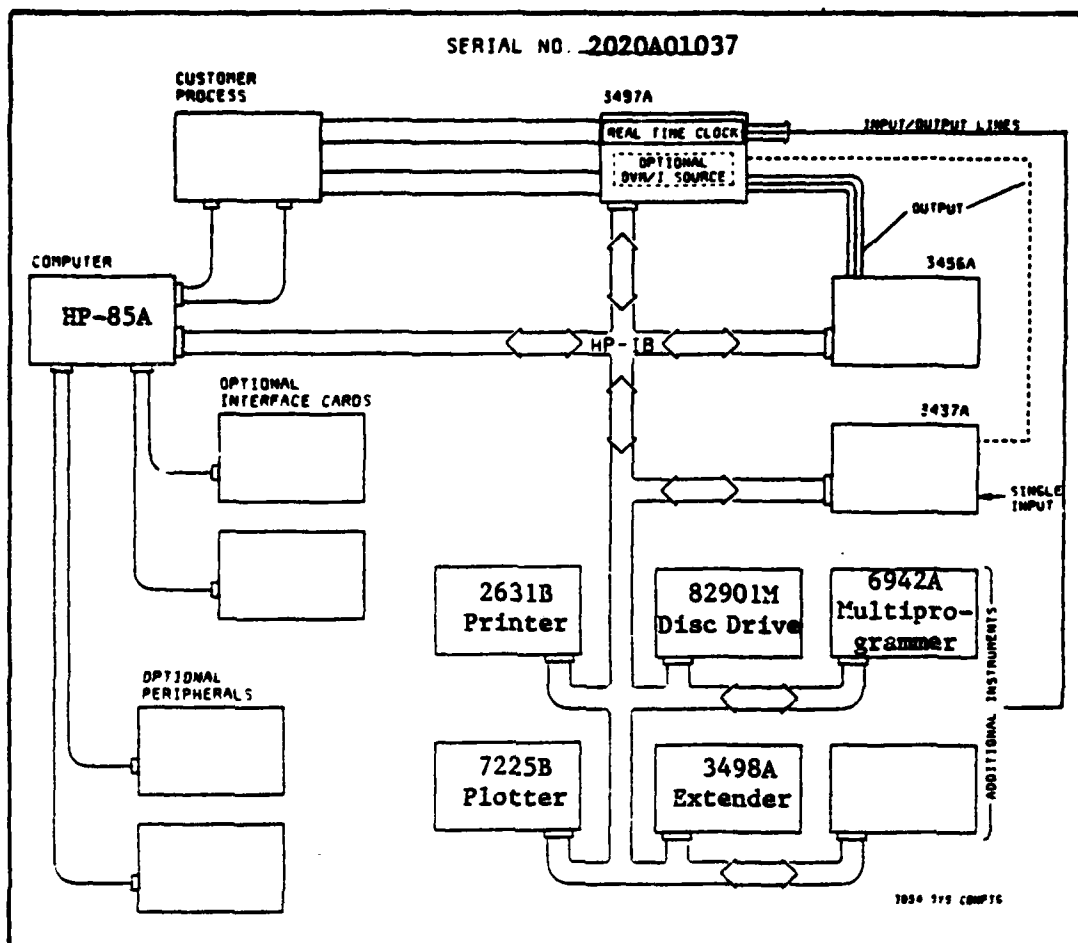
Figure 1 shows a system block diagram of the Hewlett-Packard 3054A Digital Data Acquisition System. The heart of this system is the HP-85 microcomputer functioning as system controller, although any computer compatible with the Hewlett-Packard Interface Bus (HPIB) can be substituted or connected to the system bus.

A description of each equipment connected to the bus is described below.

### A. 3054A DATA ACQUISITION AND CONTROL SYSTEM

The 3054A is a computer-based automatic data acquisition and control system. The system is complete with a system mainframe, the HP-3497A, and two voltmeters (the HP-3456A and HP-3437A), that are interfaced via the 82937A HP-IB I/O card to the powerful HP desk top computer, the 85A.

The 3054A System documentation has been designed to coordinate efficient use of each of the system instruments, and it includes a specialized software support package that



**3054A System Block Diagram.**

**Figure 1. Data Acquisition System**



is designed to use the System instruments to achieve specific functions and operations.

#### B. HP-3456A DIGITAL VOLTMETER

The 3456A Digital Voltmeter is a  $3\frac{1}{2}$  to  $6\frac{1}{2}$  digit, integrating voltmeter with relatively high speed, 10 parts per million (PPM) basic accuracy and 100 nanovolt sensitivity. Its DC and True RMS AC voltage maximum of 1000 volts and resistance measurement capability reduce the amount of signal conditioning necessary. It can detect 100 nanovolt changes in 100 millivolt signals at speeds of 48 readings per second. This capability is required for measuring thermocouples with the 3054A system to better than  $0.1^{\circ}\text{C}$  resolution. By selecting  $4\frac{1}{2}$  digits of resolution, reading rate is increased to 330 readings per second. The 3456A has selectable integration times from 0.01 to 100 power line cycles and provides input guarding to give 140 db of common mode rejection, providing for accuracy in the presence of noise. Two other noise reduction features are provided by digital averaging and an analog input filter.

Up to 350 readings can be stored in the 3456A Read/Write memory in addition to providing a programmed time delay between readings. A "voltmeter complete" signal provides the necessary means to synchronize the operation of the 3456A with the 3497A to allow analog scanning rates up to 300 channels per second.

### C. 3437A DIGITAL VOLTMETER

The 3437A is a high speed,  $3\frac{1}{2}$  digit, DC voltmeter which provides precisely timed sample and hold readings. It can perform a variety of tasks from scanning DC inputs to AC waveform analysis. Repetitive signals with frequency components up to 1 MHz and low frequency transients longer than 500  $\mu$ sec can be rapidly digitized and analyzed. Parameters such as RMS value, residual DC, harmonic content, and peak values can be readily and automatically determined.

Using the HP-85 controller and a "Fast Handshake" transfer mode of operation, reading rates of up to 4000 readings per second are possible in the packed binary mode of operation.

### D. 3497A DATA ACQUISITION/CONTROL UNIT

The 3497 data acquisition/control unit combines precision measurement capability with control functions. It can provide precision measurements of strain gauge outputs, thermocouples, pressure transducers, and other sensors, and can also provide digital interfacing and control. A digital clock is built into the 3497A mainframe for real time control applications.

Five slots are available for plug-in I/O card options on the 3497A mainframe. Additionally, the 3497A capabilities may be expanded through the addition of one or more 3498A Extenders. Up to 1000 analog channels and 1300 digital channels can be obtained with the addition of 14 3498A Extenders. Each extender has 10 slots for plug-in I/O card options.

The 3497A mainframe also provides several key features that make it very suitable for use in computer controlled data acquisition systems. The following TTL compatible input and output terminals are standard on the 3497A: external trigger input, external increment input, break before make (BBM) sync pulse (input/output), voltmeter complete output signal, channel closed output signal, and a timer signal. Additionally, the 3497A has multiple programming commands providing versatility in process control applications.

#### E. 3498A EXTENDER UNIT

The capacity of 3497A mainframe may be expanded through the addition of from one to fourteen 3498A extender units, each having 10 slots in its frame for I/O modules of various types to meet specific application requirements.

Special attention to the 3498A extender operating manual is required when adding additional I/O cards. Slot numbers 5 through 9 do not exist for digital cards.

#### F. HP-82901M FLEXIBLE DISC DRIVE

The mass storage requirements for the system are handled by the 82901M dual-drive disc system which supports two 5 $\frac{1}{4}$  inch flexible double-sided, double density discs, providing a total of approximately 550K bytes. Drive #0 is established as the default mass storage medium. Over 220K bytes of mass storage are also available in the HP-85 internal cassette tape drive.

#### G. HP-7225B PLOTTER

The HP-7225B plotter contains a 17601A personality module and is therefore a microprocessor based HP-IB plotter that produces high quality graphic plots on any size chart up to 210 x 297 mm.

Pen movement is as small as .032 mm for high resolution plotting. The plotter instruction set includes 39 different instructions to provide such capabilities as point digitizing, labeling, character sizing, scaling, and window plotting. The 7225 is interfaced through the HP-IB providing extreme versatility.

Pen velocity is programmable from 10 mm/sec to 250 mm/sec. Seven different dashed-line formats, symbol mode plotting and user defined characters aid in trace identification.

#### H. HP-2631B LINE PRINTER

The 2631B is a 180 character per second printer that produces high resolution dot matrix printing. Characters are printed from one of two 128 ASCII character sets. A 16 channel fixed or programmable vertical forms control (VFC) is available for any desired page and text length with several print pitches to select from. An underline mode is also available.

The 2631B uses a bidirectional printing head and, additionally, monitors incoming data to determine optimum print direction for the next line. Other features include blank

space detection and suppression, eight print densities with underlining, automatic vertical and horizontal tab settings and margins. It also includes an end of line (EOL) wrap-around feature. When the printer receives data which would cause printing to exceed the right margin, it automatically moves the data (which would ordinarily be lost) to the next line.

#### I. HP-85A COMPUTER

The heart of the Data Acquisition system is the 85A desktop computer which functions as system controller. The computer is interfaced with system components via the 82937 HP-IB I/O card. The 85A uses enhanced BASIC programming language and supports the PLOTTER/PRINTER ROM, INPUT/OUTPUT ROM, MATRIX ROM, and the MASS STORAGE ROM, providing an extremely versatile instruction set. The 85A also features a 32 x 16 CRT display with full graphics capability, an internal 32 column thermal printer, live keyboard, buffered I/O, priority intercept, high speed tape cartridge, autostart, and error trapping.

It is also a versatile calculator and can be used with virtually no previous HP-85 experience. The user can halt an executing program using the pause key, perform a series of calculations on the keyboard, print out the answer, and then resume program execution by pressing the CONTINUE key.

Reference 1 describes the HP-85 system characteristics and the extensive instruction set.

## J. HP-6942A MULTIPROGRAMMER

For high speed data acquisition applications the HP-3054A is augmented with the 6942A multiprogrammer. The 6942A is capable of functioning independently from the 3054A as a master control unit for bidirectional communication, data processing, and data transfer between an HP-IB controller (the HP-85 computer) and a multiprogrammer system. It can be used in a single-unit system employing from one to sixteen plug-in I/O cards, or in a multi-unit system consisting of one 6942A master unit and up to seven 6943A extender units. Each extender unit can accommodate up to sixteen input/output (I/O) cards, allowing a multiprogrammer system to be expanded to 128 I/O cards.

The 6942A employs 32 different instructions in its instruction set, permitting a wide variety of I/O card functions under program control of an HP-IB controller. The instruction set includes system control, output, input, card control, and system timing functions. System control instructions establish the basic operating modes of the multiprogrammer system. Output instructions are used to send data to output cards while input instructions are used to obtain data from input cards. The card control instructions allow access to various circuits on the I/O cards to enable close control and monitoring of their various operations. The system timing instructions permit the sequencing of events and the measuring of elapsed time. A detailed description of the

instruction set is described in the 6942A User's Guide [Ref. 2] as well as programming details for the HP-85 controller.

In addition to the 16 I/O cards, an HP-IB interface board and a transmission system board are installed in the rear of the 6942A unit. The 6942A's internal mainframe circuitry includes a CPU/ROM board and a control/RAM board. All power supplies for the I/O card slots and mainframe circuitry are built into the 6942A unit. The CPU/ROM board includes a 16 bit microprocessor chip which decodes and executes all instructions, and controls all data transfers. The 12K x 16 bit ROM (Read Only Memory) contains the microprocessor controlled programs (firmware) required to process all instructions. The ROM also contains diagnostic programs for built-in self test and signature analysis/troubleshooting capabilities. The control/RAM board contains a 2K x 16 bit RAM (Random Access Memory) which is used for the temporary storage of instructions and data.

Backplane control circuits on the control/RAM board decode I/O card addresses and control I/O card functions. The HP-IB interface board provides the bidirectional communications interface between the 6942A and an HP-IB controller.

Three I/O card types are presently installed in the 6942A multiprogrammer: a 69736A Timer/Pacer card, two 69751A high speed analog to digital converter cards, and two 69790B 4K x 16 bit Random Access Memory cards.

### 1. 69736A Timer/Pacer Card

At power-on the timer/pacer "wakes up" in the one shot mode which produces a single output pulse with a crystal-controlled duration programmable from one micro-second to about eighteen hours (65535 seconds). Another mode (the continuous mode) can also be programmed in which the output goes high for the programmed time interval, then low for the same interval, and continuously repeats this cycle until the card is reprogrammed or disabled externally. The card's single output pulse can be used as a programmable delay or as an enable signal for a frequency counter card (69775A) in frequency measurement applications. The square wave output generated in the continuous mode can be used to pace A/D or D/A converters as they analyze or generate waveforms or to drive frequency-to-voltage converters or other devices which require a programmable-frequency square wave input.

Figure 2 [Ref. 2] shows a detailed block diagram of the timer pacer card. In the Light Scattering experiment the timer pacer card is programmed to the continuous mode and drives the external trigger input of 2 high speed A/D converter cards. The timer pacer is itself externally triggered by the Reticon Photodiode array #1 which also synchronizes the operation of Photodiode array #2.



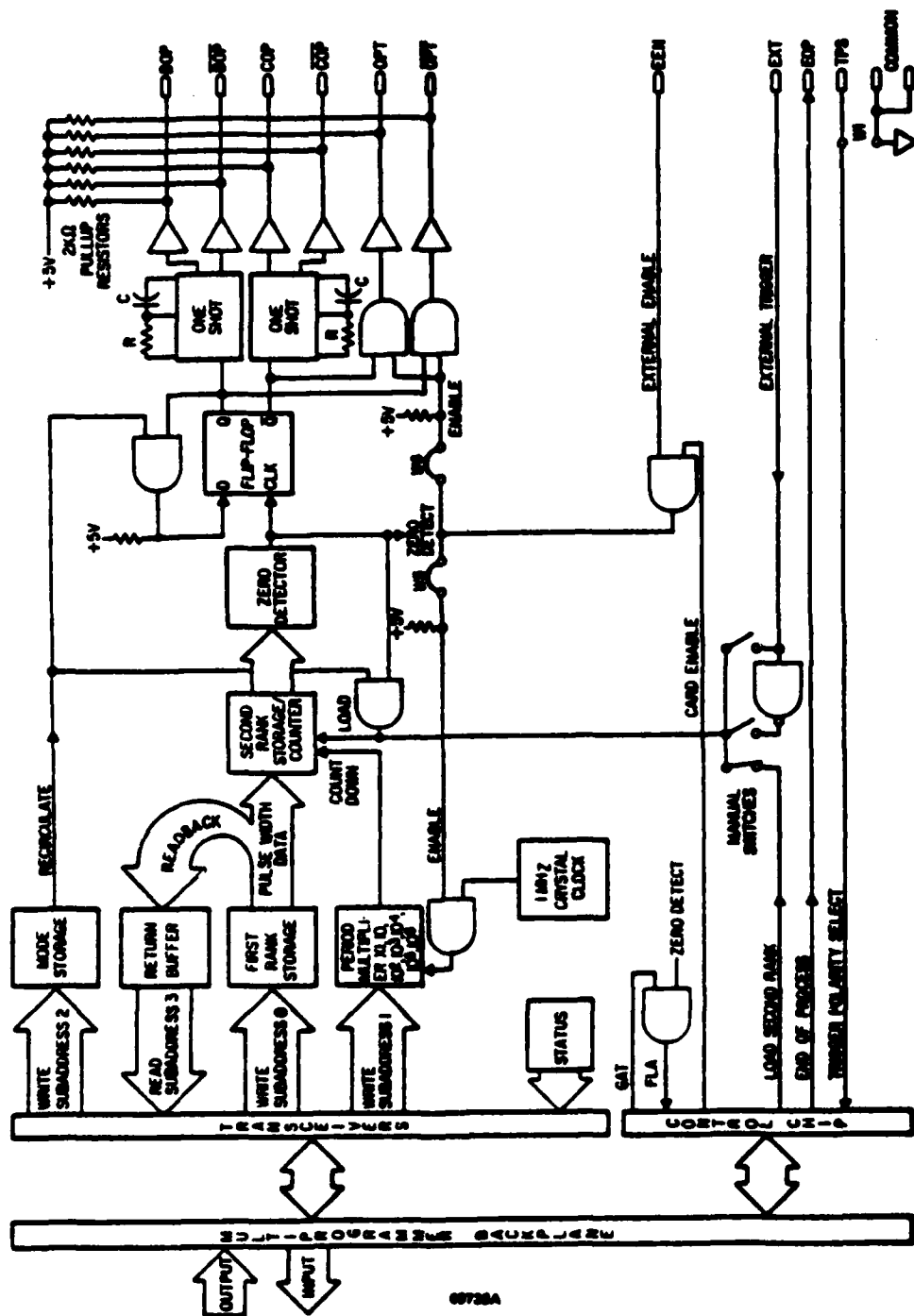


Figure 2. Multiprogrammer--Timer/Pacer  
[Ref. 2]

## 2. Analog to Digital Converter Card #69751A

The 69751A is a 12 bit, analog to digital (A/D) converter used to measure bipolar DC voltages in one of four ranges:  $\pm 100$  MV,  $\pm 1$  V,  $\pm 10$  V, or  $\pm 100$  V. A voltage measurement can be initiated by a programmed instruction or by an external trigger signal. Three manual range switches on the card select either the  $\pm 100$  MV,  $\pm 1$  V, or the  $\pm 10$  V range. Input voltages in the  $\pm 100$  V range are connected to the card's divide-by-ten attenuator. Sixteen optional DC input ranges (8 bipolar and 8 unipolar) are also available. Instructions for modifying and recalibrating the A/D card for the optional DC input ranges are described in section 11 of Ref. 2.

The A/D card uses a high performance sample and hold amplifier and a successive approximation A/D converter which provide a high conversion speed and excellent accuracy characteristics. The DC input voltage is guarded to maintain high input impedance. Optically coupled isolators are used to isolate the DC input voltage from the data lines.

The 12 bit digital word, indicating the magnitude and sign of the measured voltage, is stored on the card and is always available for readback to the multiprogrammer mainframe memory using card subaddress 0. As many as 1339 readings can be stored at one time in mainframe memory. The multiprogrammer firmware converts the digital word decimal form for readback to the controller. The controller can

read back the voltage value using appropriate HP-IB extended talk address.

The use of Extended Talk Addresses and other secondary addressing with the HP-85 computer requires the custom HP-IB command "SEND" which is described in detail in the HP-IB I/O programming manual [Ref. 3].

The 12 bit data word (voltage reading) is routed to the A/D's edge connector so that the A/D can be used in conjunction with the 69790B memory card to make measurements at rates that exceed the throughput of the controller. Up to 33000 readings per second can be transferred from the A/D converter to the memory card via the edge connectors on each card. Each reading can be initiated by program commands or by an External Trigger (EXT) signal.

Either the 69736A Timer Pacer or the 69735A Pulse Train Output card can be used to externally trigger the A/D converter. The 69736A Timer/Pacer is programmed in a convenient seconds-milliseconds-microseconds format for programmable delay or continuous triggering.

Figure 3 shows the functional block diagram of the 69751A Analog to Digital converter card. Various subaddresses can also be written using the software described in section 5 of the User's Guide [Ref. 2].

### 3. Memory Card #69790B

The 69790B Memory Card is a FIFO (first in first out) buffer that can handle a continuous stream of data that is



being transferred from the outside world to the controller or from the controller to the outside world. In another operating mode, the recirculating input mode, it can act as a circular buffer that continuously stores data coming in from the outside world until it is programmed to stop accepting new data. At this time it contains the last 'n' words of data received, 'n' being the capacity of the card. One more operating mode, the recirculating output mode, allows all or part of the memory contents previously acquired to be read repeatedly by an external device.

Each 69790B memory card consists of two plug-in cards that occupy two adjacent slots in the mainframe. The card designated card #1 occupies the left-hand slot and communicates with card #2 through a cable.

A memory card assembly can communicate bidirectionally with the controller and with an external device connected to the edge connector on card #1 of the pair. External data transfers through 16 input or 16 output lines and are controlled by means of three input or three output handshake lines. Special purpose Memory Input (MI) and Memory Output (MO) instructions allow data transfers to be made between the controller and a memory card assembly without storing the data in mainframe memory.

In a system that contains more than one memory card assembly, each assembly can handle data transfers to or from the outside world simultaneously with external data transfers

being made by the other assemblies. Absolutely no interactions occur between their external interfaces. An external interface is independent not only of the other external interfaces, but also of any other card or mainframe activity. Thus, within a single assembly, an external device can write to a memory card while the controller is reading from another part of the same card, or an external device can read from a memory card while the controller is writing to another part of the same card. Through the use of controller interrupts or another means of program control, data can be loaded into memory and read from memory on a continuous basis in either an input or an output operation.

Figure 4 is a functional block diagram of the 69790B memory card.

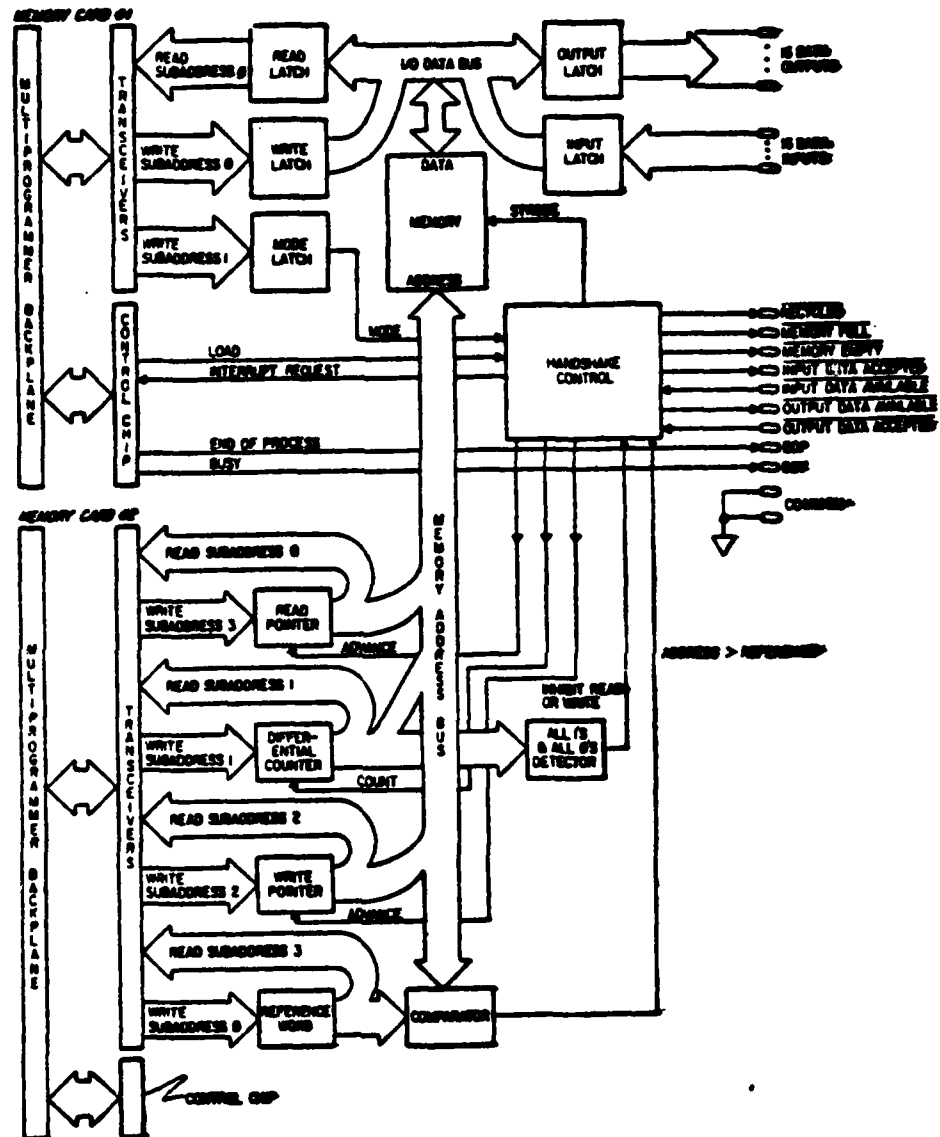


Figure 4. Multiprogrammer--Memory Board [Ref. 2]

### III. PARTICLE SIZE DETERMINATION BY LIGHT SCATTERING OF A HELIUM NEON LASER BEAM

The purpose of this experiment is to determine the volume to surface mean diameters ( $D_{32}$ ) of particulate matter in the exhaust plume and combustion chamber of a solid propellant rocket motor.

The equipment test set up is shown in Figure 5. Reference 4 provides extensive information on the physical principles involved and a description of the optics system.

The helium neon laser is remotely controlled under software control and radiates a beam at a wavelength of 0.6328 micrometers. The beam is then expanded and collimated. It is then passed through a limiting orifice to reduce the beam diameter to 2.2 millimeters.

The beam is subsequently passed into a beam splitter where one beam is turned through 90° and routed through a window in the rocket motor casing. The other beam is aligned directly in the exhaust stream of the rocket motor approximately two inches behind the nozzle throat.

Each beam is passed through a focusing lens and directed through a narrow pass filter to the edge of a linear array of photodiodes.

Two EG&G RETICON G Series Solid State Line Scanners are used, each containing 1024 photodiode elements. The Reticon



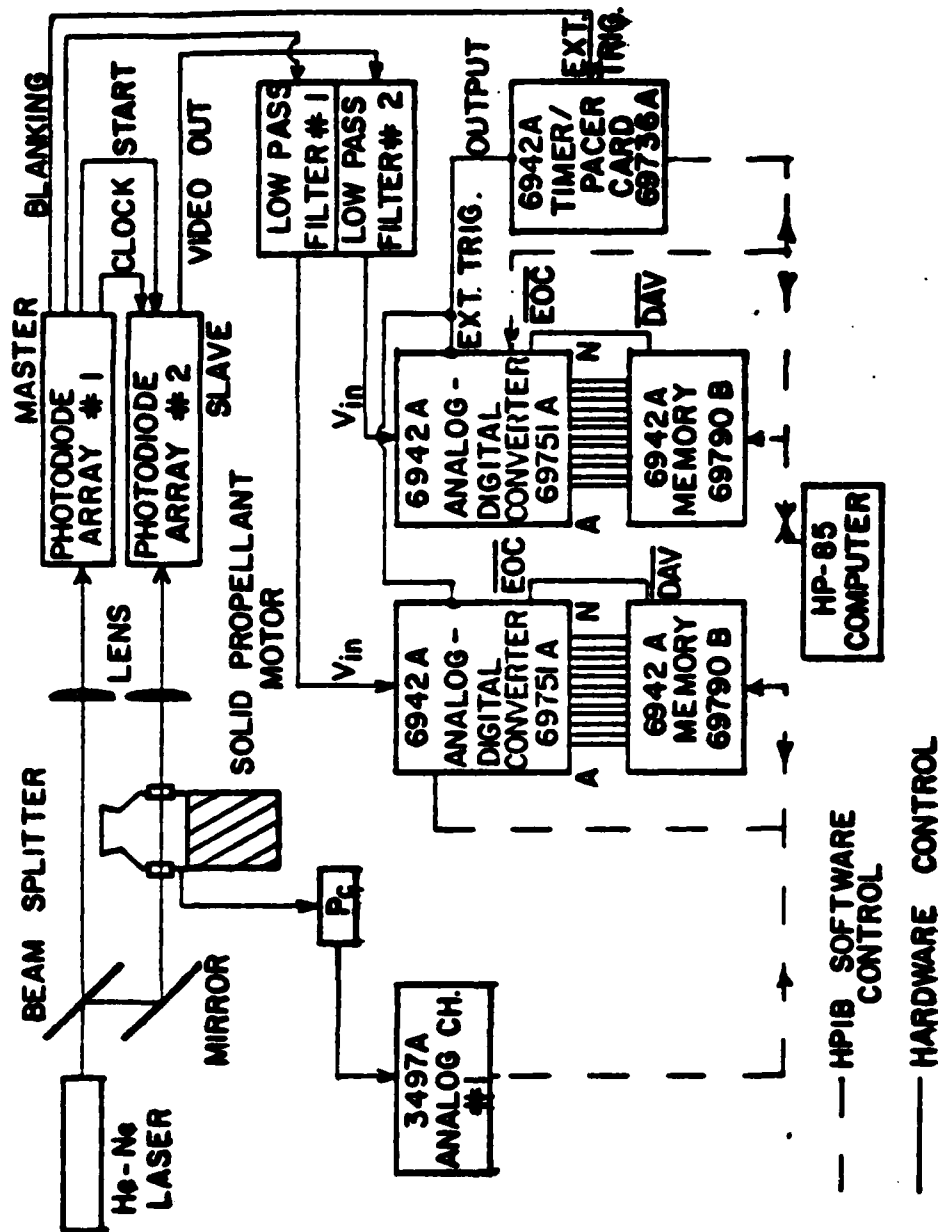


Figure 5. Particle Size Determination System Diagram

RL1024G series photodiode array is optimized for solid state image sensor applications. It contains 1024 diodes arranged in a linear array on 25 micron centers. Diode #1 is normally set 1.54 millimeters off of the laser beam centerline to reduce the amount of transmitted light present, and to allow for increased sensitivity to the diffracted light pattern.

The G series array is connected through an RC-100/106 sample and hold "Boxcar" circuit which provides its own clock oscillator for self scanning, although provisions for externally pacing the array with an external clock signal are installed.

Photodiode array #1 (Fig. 5) is operated in the internal clock/internal start mode and is completely independent. The internal clock oscillator is set to approximately 30 KHz. To prevent integrated "dark current" from making a significant contribution to the output charge the total time between start pulses should be kept less than about 40 milliseconds.

The countdown circuit on the array board counts 'n' clock pulses to generate a start pulse in the internal start mode. The countdown switches are initially set according to the formula:

$$n = t_L \cdot f_C$$

where  $t_L$  = time between start pulses in seconds

$f_C$  = clock frequency in Hz

n = switch setting

$$\text{e.g. } n = 36(10^{-3}) \cdot 30(10^3)$$

$$n = 1080$$

A countdown switch setting of 1080 to 1 will provide a time between start pulses of 36 milliseconds at a clock frequency of 30 KHz, and excessive "dark current" error build-up is avoided.

Photodiode array #2 monitors the second laser beam which emerges from a window in the rocket motor body. Array #2 operates in the external clock/external start mode and is a slave to photodiode array #1. Therefore, the countdown circuits in array #2 are not used. Array #2 has only one output, the video "boxcar" signal representing the photodiode voltage output which is routed directly to A/D converter #2 in the 6942A multiprogrammer.

The boxcar voltage outputs from the photodiode arrays are routed through analog low pass filters which pass all signal components less than 3000 Hz. 20 db gain is attained in the low pass filter amplifier. The filtered outputs are routed to the voltage input terminals (+W, -Y) of the high speed analog to digital converters located in the 6942A multiprogrammer. When a series of readings are desired the HP-85 programs the 69736A timer to output a square wave output at approximately 30 KHz when externally triggered by the blanking pulse output from photodiode array #1.

The square wave output from the timer pacer card is directed to the external trigger inputs of both 69751A high

speed (A/D) cards which begin making 1024 conversions of the analog voltage present at terminals (+W, and -Y). The 12 bit digital outputs from terminals A through N are hard wired to the corresponding edge connector pins of the 69790B, 4K memory cards associated with each (A/D) card. The memory is programmed to accept a 12 bit format and to store 1024 readings in a first in first out (FIFO) input mode. The memory card is then armed to interrupt the computer after 1024 readings have been stored on the card. The (A/D) card performs a conversion of the analog voltage at its input terminals (W, Y) every time it observes a trigger from the timer pacer card at its external trigger terminals (m) at a rate of 30 KHz. The (A/D) card signals the completion of each reading by outputting an end of conversion (EOC) and its complement ( $\overline{\text{EOC}}$ ). The  $\overline{\text{EOC}}$  is connected to the data available ( $\overline{\text{DAV}}$ ) terminal of each 69790B memory board.

The procedure employed for an experiment is outlined below. Figure 6 presents a flow diagram of the system. After applying power, the HP-85 is loaded with a program disc in drive #0 and a data disc in drive #1. The program named "HELP" is loaded and run to initialize variables and provide documentation. At the completion of "HELP" the next program is automatically loaded and executed by a process called chaining, which allows a program of virtually unlimited length to be run in the limited memory space of 32K of the HP-85

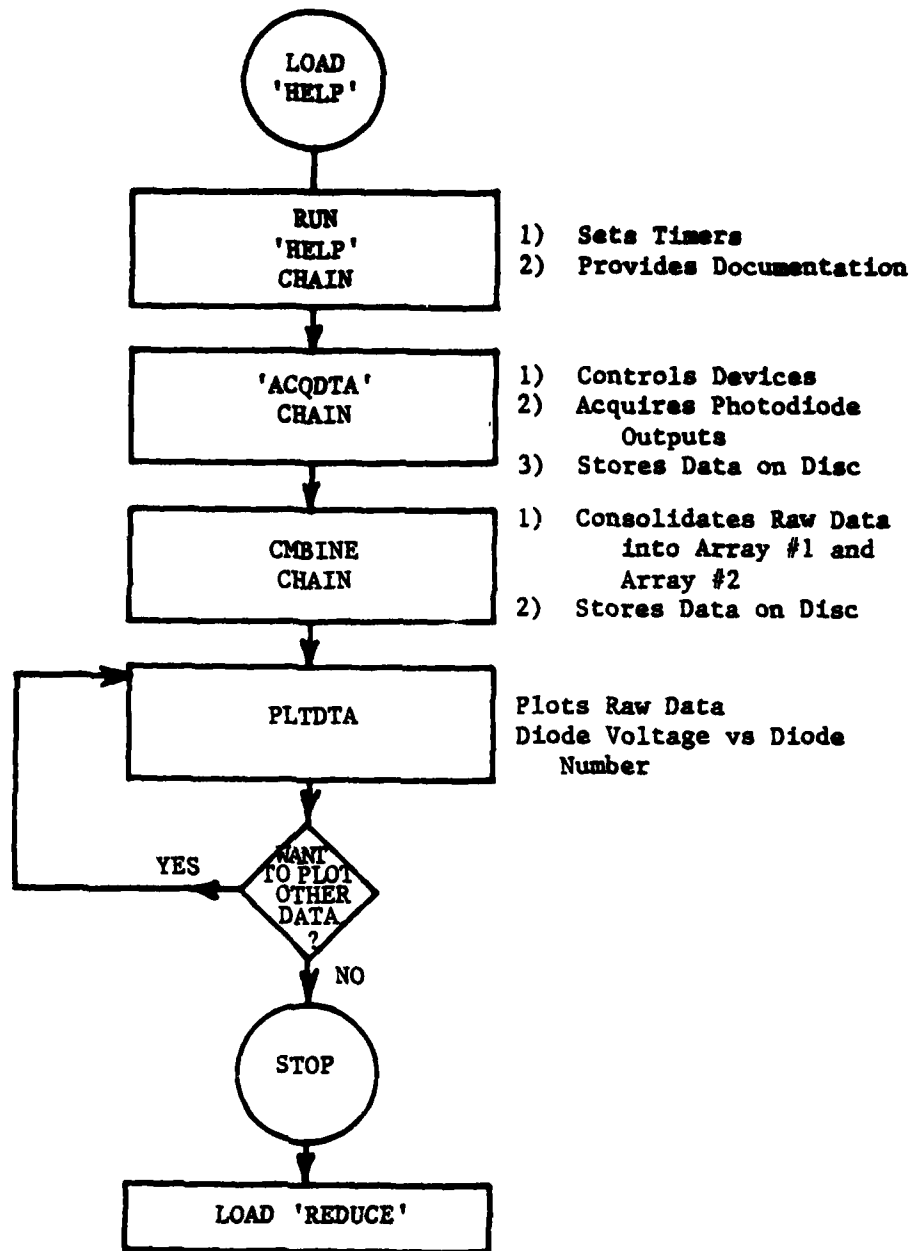


Figure 6. Light Scattering Program Flow Chart--Part One

computer. "ACQDTA" now performs the process control, system timing, and data acquisition tasks.

First, the laser is energized, data files are created with user specified file names, and initial readings are taken from both photodiode arrays by software command. Each array simultaneously sends its output to its 69751A (A/D) converter in the 6942A multiprogrammer. Each (A/D) card is externally triggered every 33 microseconds by the 69736A Timer/Pacer card and converts the analog voltage present at terminals (+W, -Y). The resulting 12 bit digital output is sent to a 69790B (4K) memory card. Each memory card is programmed to store sequentially 1024 readings and to interrupt the computer after 1024 readings have been stored. At this time the numerical data are transferred via the HP-IB to the controller, first array #1 then array #2. This raw data represents the "no particle" or "zero scattering" condition.

The "no particle" numerical arrays are then stored as a data file on the disc to preclude loss of the data.

The computer then performs a continuity check of the firing circuit using the 3456A in a resistance measurement mode. After a successful continuity check, the 3456A is programmed to record DC voltage. It is connected to the firing switch while displaying (on the HP-85), "STANDING BY FOR IGNITION", and energizes the nitrogen purge for the motor windows. When the operator closes the ignition switch a

voltage greater than 10 volts is sensed by the 3456A and causes the computer to energize the drive motor of the visicorder, which records the chamber pressure-time trace.

Once the computer senses the ignition sequence it connects the 3456A to the pressure transducer in parallel with the visicorder trace.

When the combustion pressure rises to a user specified threshold pressure in (PSI) the computer delays or waits a user specified number of seconds, and triggers the multiprogrammer to acquire a new data set from the photodiode arrays. When the data are taken a pulse output voltage (TTL) is sent to another visicorder channel as an event marker signal to indicate data acquisition time on the pressure-time trace. Readings taken during the rocket motor burn time will be different than pretest readings since particulate matter is present in the gas stream. This data is transferred to the computer and then to a data file on the data disc as before.

After 5 seconds the visicorder is disengaged, the window nitrogen purge turned off, and the laser is deenergized. The next program is chained.

"CMBINE" is automatically loaded and run. This program executes disc operations which read the "no particle" data and the "particle" data into the computer. It then separates this data into photodiode array #1 data and photodiode array #2 data with the same file names as previously specified by the user. Each file contains 1024 records, each containing

two numbers, a "no particle" and a "particle" voltage. The computer prints a reminder of which data is in which data file and then chains the next program segment.

"PLTDTA" plots the data from a data file specified by the user, plotting diode voltage output versus diode number (Fig. 7). The operator can elect to plot the other data file or load and run the data reduction program.

The operator is then prompted to load and run "REDUCE" to begin the reduction of the raw data. Figure 8 shows a flow chart for the data reduction process. "Reduce" functions to compute a normalized intensity vector and an angle theta vector. The theta vector is computed based on diode number (1 to 1024), lens focal length, and the index of refraction of the media containing the particles by the formula:

$$\theta = \frac{K_1 + n(.025)}{F m} \text{ radians}$$

where  $K_1$  = the distance from the centerline of the laser beam to the centerline of diode #1 (mm)

$n$  = diode number (1 to 1024)

$F$  = lens focal length (mm)

$m$  = index of refraction

air = 1.0

water = 1.35

.025 = distance between diode centers (mm)

Upon examination of the "PLTDTA" results, the location of the peak intensities are printed. The user is then prompted for the diode locations where the slope is to be determined



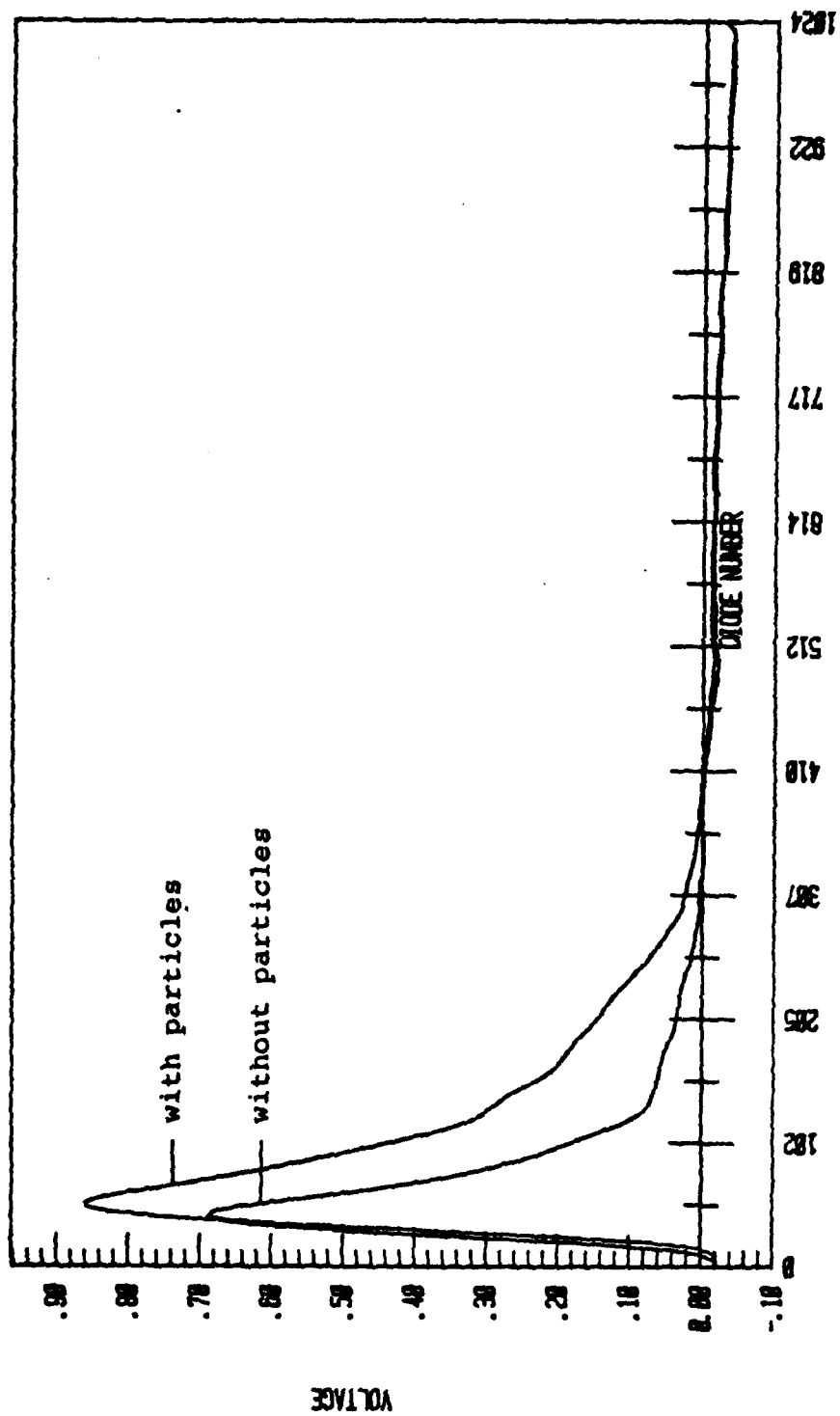


Figure 7. PLTDTA Output--Voltage vs Diode Number

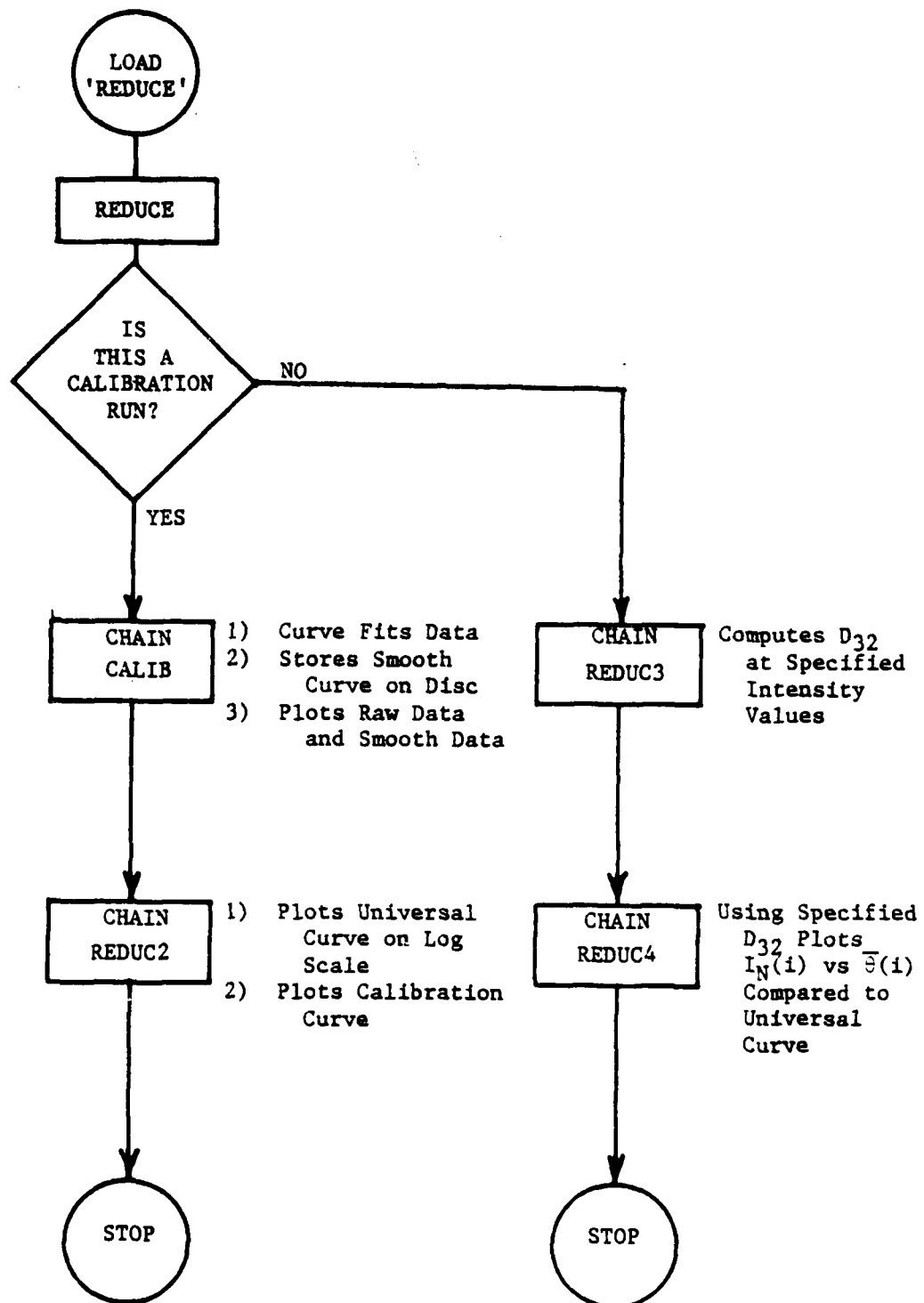


Figure 8. Light Scattering Program Flow Chart--Part Two

and then projected back to obtain a centerline value for the scattered laser power using a linear regression technique.

First, the "zero scattering" data is subtracted from the "with particle" data. The resulting 1024 element vector is then regressed against diode number to obtain the intensity-axis intercept representing the centerline value by the following formula:

$$nA + BX_1 = Y_1$$

$$X_1A + BX_2 = Y_2$$

where  $A$  = intensity-axis intercept

$n$  = number of data points

$B$  = slope of intensity vs theta line

$$X_1 = \sum_{i=1}^n \theta_i$$

$$X_2 = \sum_{i=1}^n \theta_i^2$$

$$Y_1 = \sum_{i=1}^n I_i$$

$$Y_2 = \sum_{i=1}^n I_i \theta_i$$

and subsequently, a normalized intensity vector is formed as:

$$I_{\theta\text{NORM}} = \frac{(V_{\theta P}(i) - V_{\theta NP}(i))}{(V_{CLP} - V_{CLNP})}$$

where  $i = 1$  to 1024

$I_{\theta\text{NORM}}$  = normalized intensities

$V_{\theta P}(i)$  = voltage with particles (vector)

$V_{\theta_{NP}}(i)$  = voltage without particles (vector)

$(V_{CLP} - V_{CLNP}) = A$  (previous calculation)

The normalized intensity is then plotted on the 7225B plotter versus the theta vector in radians (Fig. 9). This data is then stored on disc for future use in a user specified file. The operator is then asked if this run is to be a calibration curve; if yes, then a curve fitting program "CALIB" is automatically loaded and executed.

"CALIB" performs a tenth order polynomial curve fit to the data set specified by the user in order to generate a smooth curve for future comparison purposes with both the universal (i.e. theoretical [Ref.4]) curve ("UNICUR") and other raw data runs. The user first enters the "D bar" value, i.e. the average diameter of the particles being used for the calibration.

A theta bar vector is then computed from the theta vector as follows:

$$\bar{\theta}_i = \frac{D_{32} \pi \theta_i}{\lambda}$$

where  $\theta_i$  = theta vector (1-1024) (radians)

$D_{32}$  = D bar (microns) mean volume to surface diameter

$\lambda$  = .6328 (microns) wavelength

Normalized intensity is then plotted versus the non-dimensional theta bar ( $\bar{\theta}$ ) as in figure 10. The user is then asked to enter the minimum and the maximum theta bar of

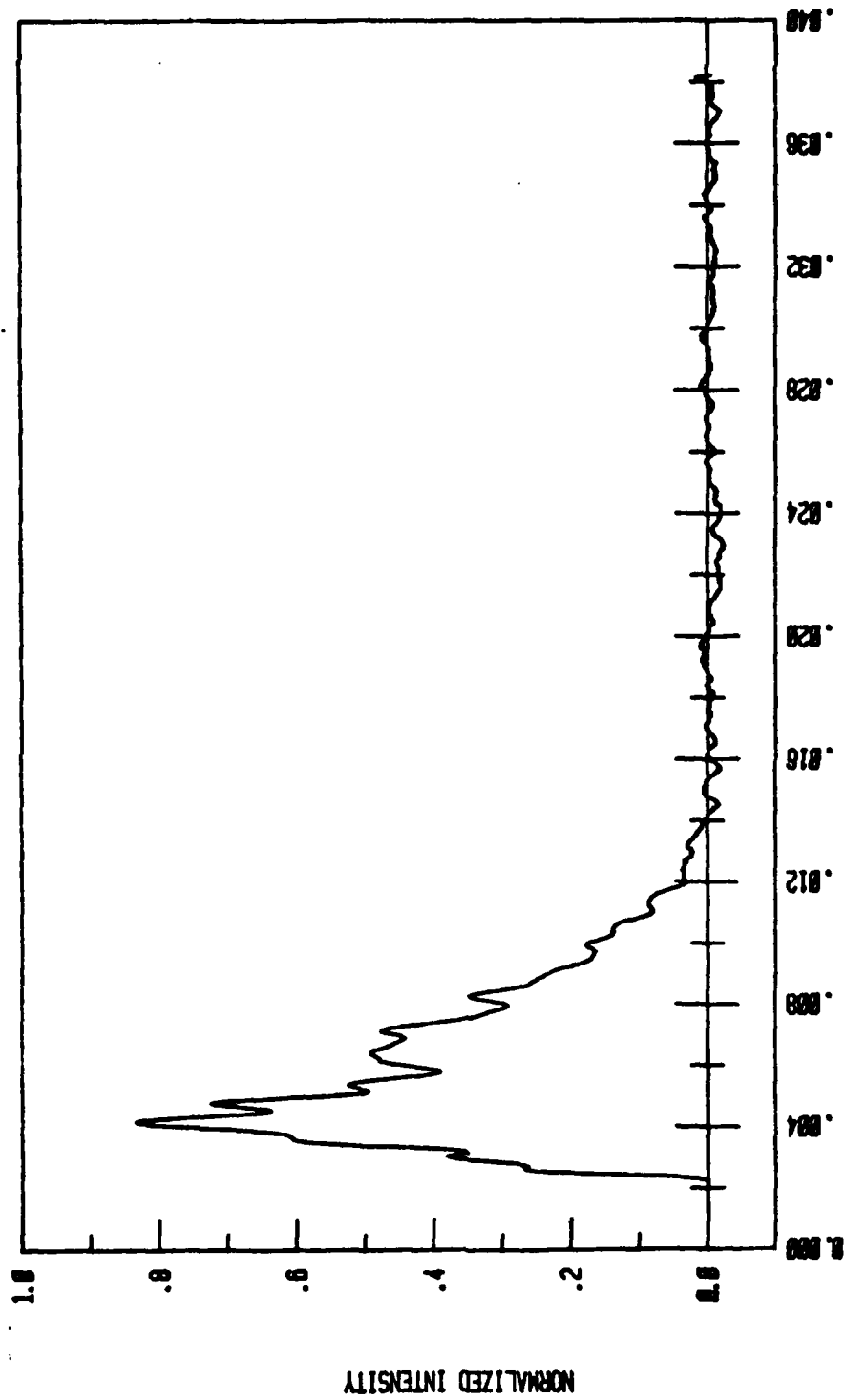


Fig. 9 REDUCE Output Normalized Intensity vs Theta

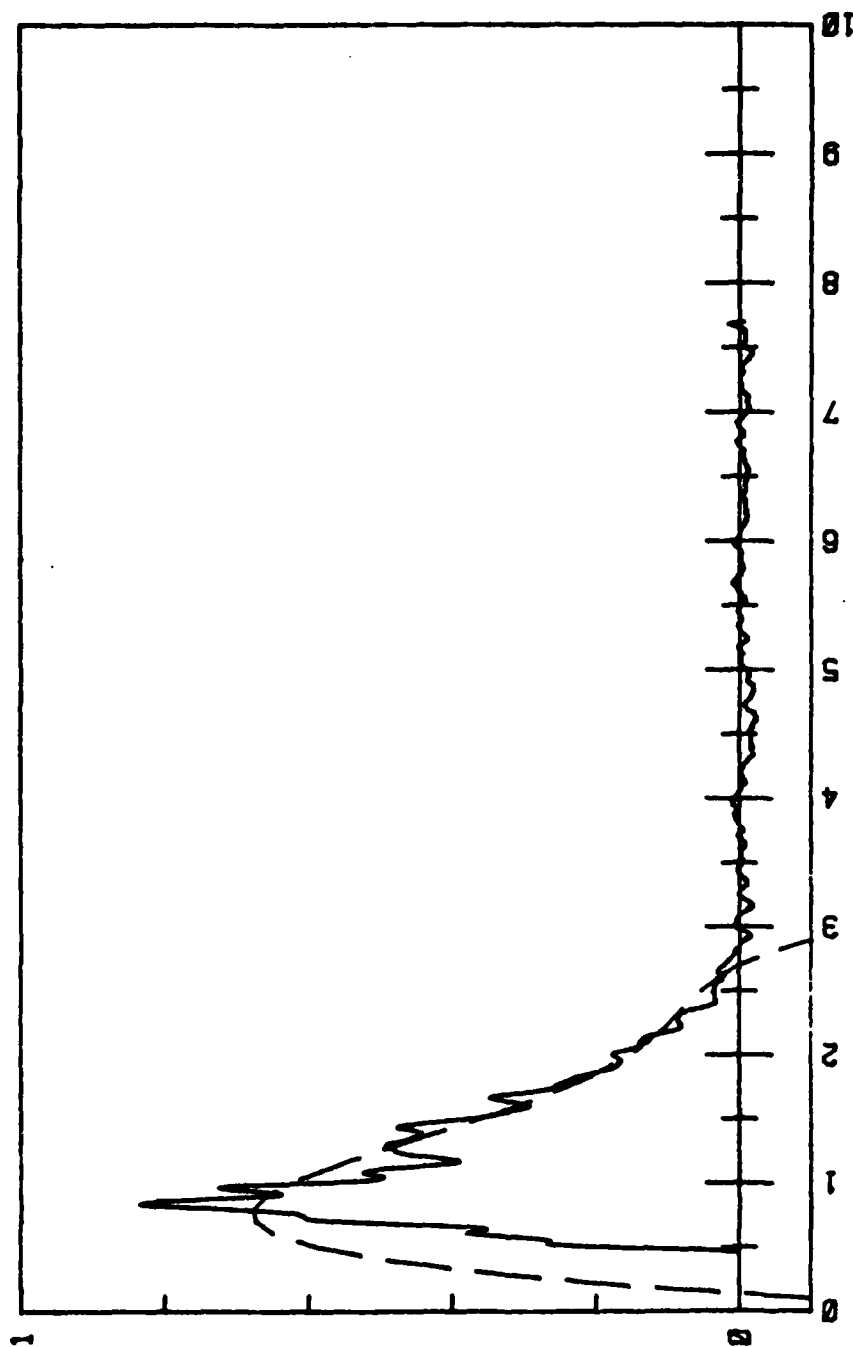


Fig. 10 CALIB Output--Normalized Intensity vs.  $\bar{\theta}$

interest. The data is regressed to form a smooth curve fit with a polynomial of up to tenth order as specified by the user and taking the form:

$$I_N = b_0 + b_1\theta + b_2\theta^2 + b_3\theta^3 + \dots + b_m\theta^m$$

where the coefficients are obtained by solving the system of  $m+1$  equations

$$\begin{aligned} nb_0 + b_1 \sum_{i=1}^n \theta_i + b_2 \sum_{i=1}^n \theta_i^2 + \dots + b_m \sum_{i=1}^n \theta_i^m &= \sum_{i=1}^n I_i \\ b_0 \sum_{i=1}^n \theta_i + b_1 \sum_{i=1}^n \theta_i^2 + b_2 \sum_{i=1}^n \theta_i^3 + \dots + b_m \sum_{i=1}^n \theta_i^{m+1} &= \sum_{i=1}^n I_i \theta_i \\ \cdot &\cdot \cdot \cdot \cdot \\ \cdot &\cdot \cdot \cdot \cdot \cdot \\ \cdot &\cdot \cdot \cdot \cdot \cdot \\ b_0 \sum_{i=1}^n \theta_i^m + b_1 \sum_{i=1}^n \theta_i^{m+1} + \dots + b_m \sum_{i=1}^n \theta_i^{2m} &= \sum_{i=1}^n I_i \theta_i^m \end{aligned}$$

Once the polynomial coefficients have been determined, a smooth 100 element curve is computed, plotted and stored on the disc in a user specified file.

The smooth curve is plotted on top of the intensity vs theta bar plot (Fig. 10) to show the correlation, which is routinely excellent. If desired, this data file containing smooth curve data can be saved permanently on the floppy disc.

"REDUC2" is automatically loaded and executed upon completion of "CALIB". The function of "REDUC2" is to plot the universal theoretical curve (datafile "UNICUR") on a three

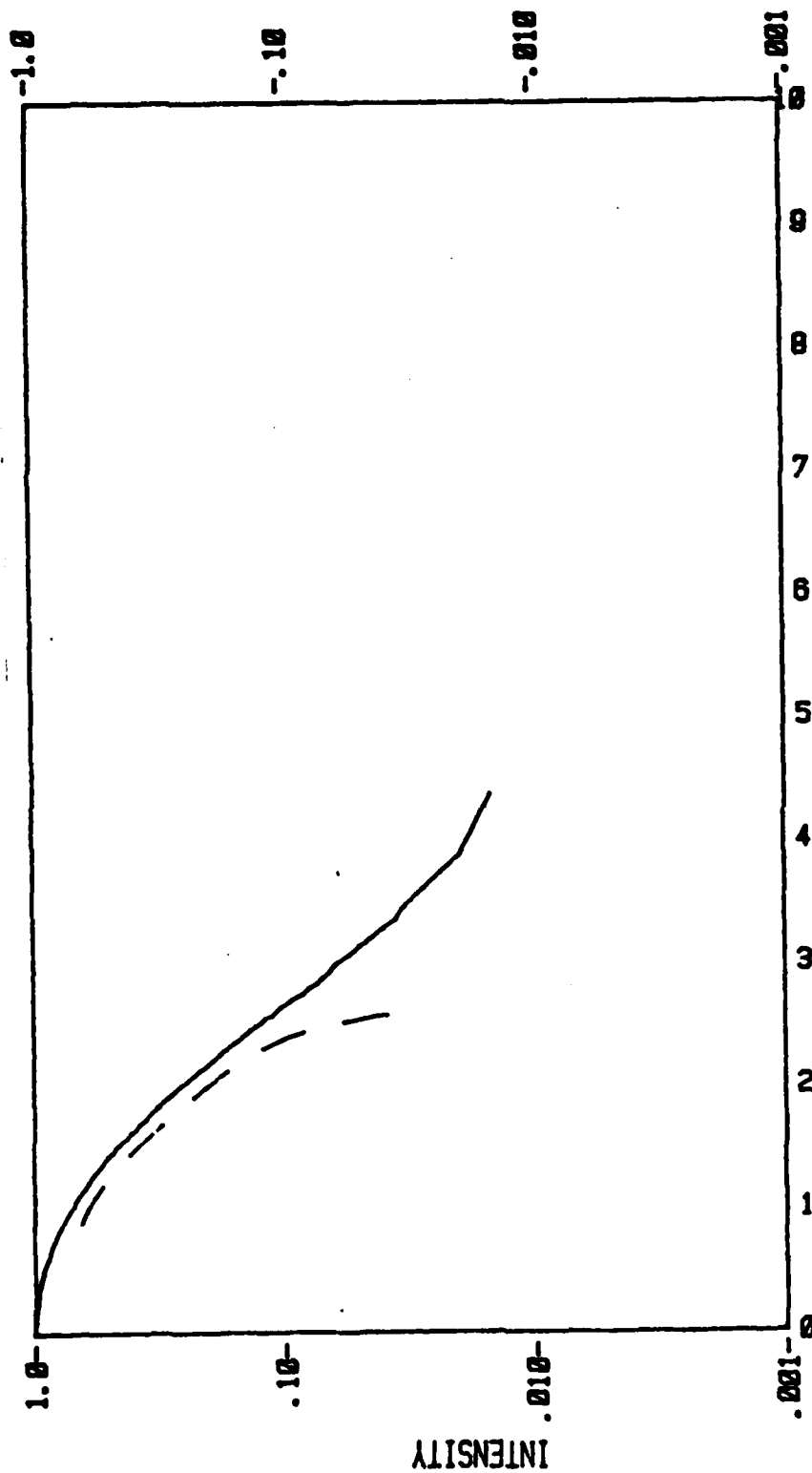
cycle semi-logarithmic scale (Fig. 11). After the theoretical curve is plotted the user may elect to plot any other calibration curve for comparison purposes (Fig. 11).

At the conclusion of "REDUCE", if the operator had not designated a run as a calibration run, the next data reduction program is chained.

"REDUC3" functions to compute  $D_{32}$  from the normalized intensity and theta data by comparing the data to specified reference curves (UNICUR, etc.) at 15 preset intensity levels. An average  $D_{32}$  is computed across this range of intensity levels. REDUC3 has tabular output only.

REDUC4 can be run, if desired, to plot a data run on a semi-log scale with a user defined  $D_{32}$  to compare with the Universal curve.





THETA BAR  
Fig. 11 REDUC2 Output- Universal curve vs theta bar  
and Calibration curves

#### IV. VITIATED AIR HEATER

A schematic of the vitiated air heater system at the combustion laboratory is shown in figure #12. It was designed to supply air at any desired mass flow rate within the system limitations (approximately 4 lbm/sec) and at any temperature up to approximately 1500°R. The heater output air is routed to the input sections of the Solid Fuel Ramjet or the Turbojet combustor.

The vitiated air heater is fueled by gaseous ethylene and bottled oxygen replaces that consumed in the combustion process. Large high pressure air tanks act as the primary air supply and the mass flow rate is determined using a sonically choked converging nozzle.

The data acquisition system was designed to monitor and control the operation of the air heater in order to provide the desired air flow rate and temperature and to provide built-in system safety.

Two Hastings precision flowmeters and two Hastings flow controllers were installed to accurately meter and control the oxygen and ethylene flow rates to achieve the desired fuel-air ratio and oxygen make-up flow rate. Figure #13 shows the interconnection of the flowmeters and controllers.

A description of the system operation is presented below. The 'HEATER' program disc is loaded into the HP-85 data

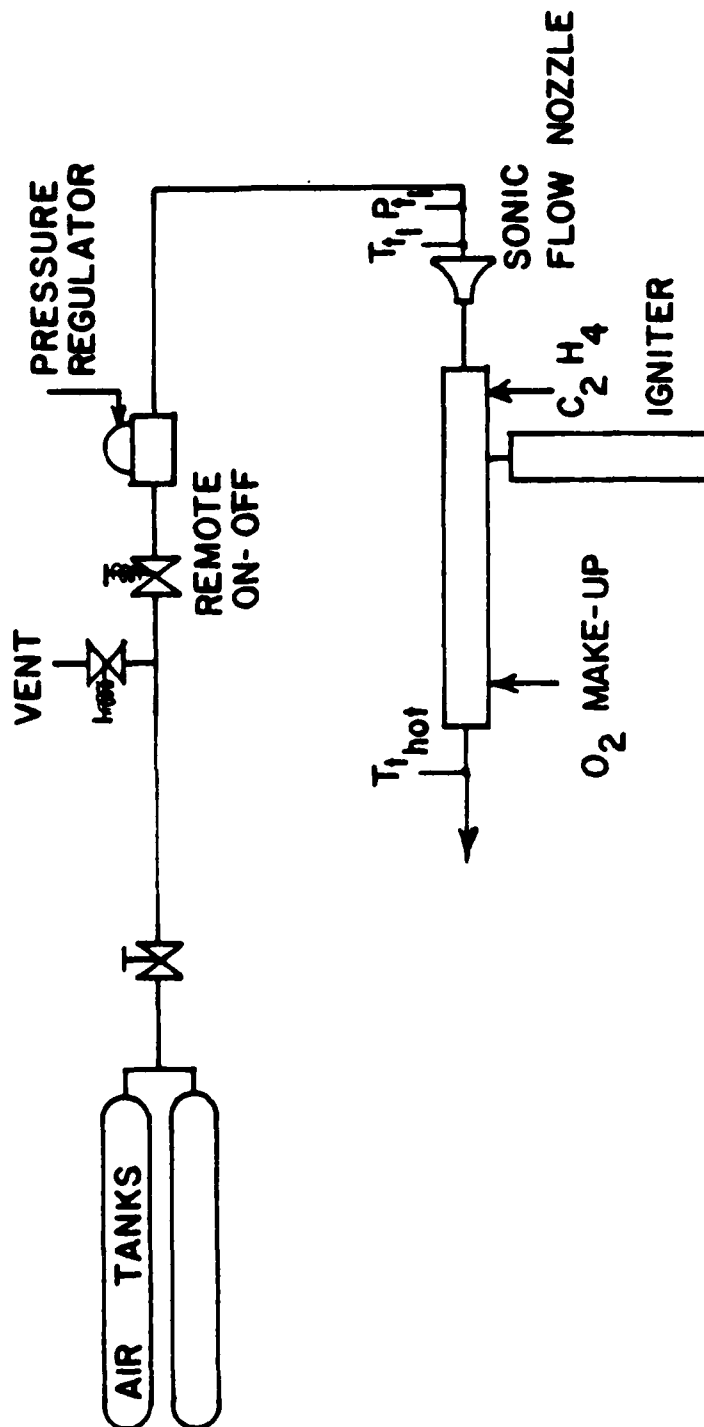


Figure 12. Vitiated Air Heater

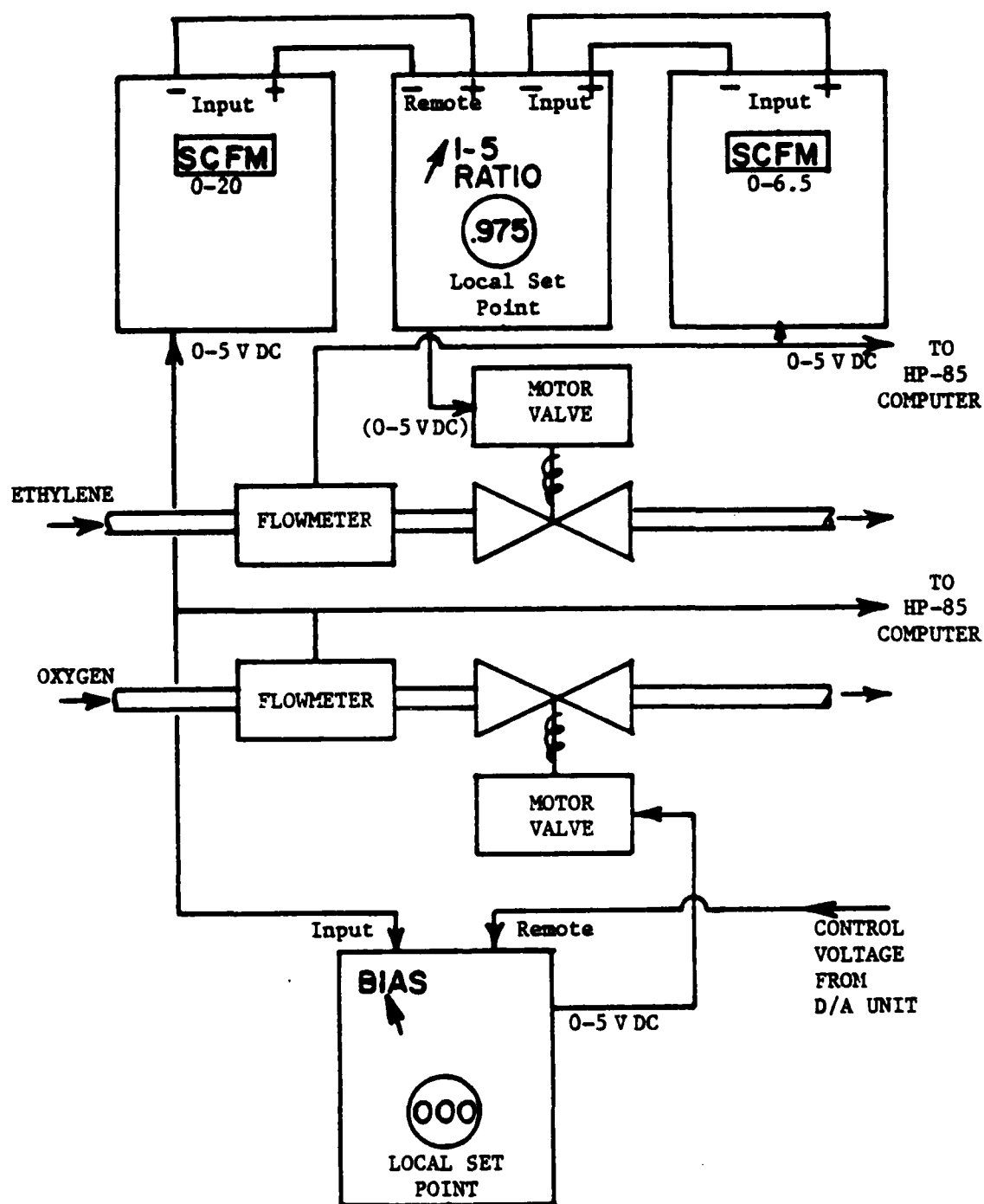


Figure 13. Flow Control Block Diagram

acquisition system. The "SET UP" option is selected to initialize variables and perform preliminary calculations to determine initial manual control settings. Figure 14 depicts the flow chart for the preliminary portion of the 'HEATER' program.

The operator inputs the desired mass flow rate of air in lbs mass/sec. Other inputs are high pressure air tank pressure (0-3500 PSIG), the estimated cold air temperature ( $^{\circ}\text{F}$ ), desired hot air temperature ( $^{\circ}\text{R}$ ), and ambient pressure (inches Hg).

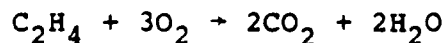
The required fuel/air ratio is then computed for ethylene and air from a regression of data obtained from the "PEPCODE" chemical equilibrium/adiabatic combustion program [Ref. 5].

$$F = \frac{T_{\text{HOT}} - 550}{78000} = \frac{\dot{m}_{\text{FUEL}}}{\dot{m}_{\text{AIR}}}$$

Once  $F$  is obtained, the ethylene and oxygen flow rates are given by:

$$\dot{m}_{\text{C}_2\text{H}_4} = F \cdot \dot{m}_{\text{O}_2} \quad (\# \text{ mass/sec})$$

For the complete combustion of ethylene with oxygen in air:



Thus, the desired mass flow ratio of oxygen to ethylene is

$$\dot{m}_{\text{O}_2} = 3.429 \cdot \dot{m}_{\text{C}_2\text{H}_4}$$

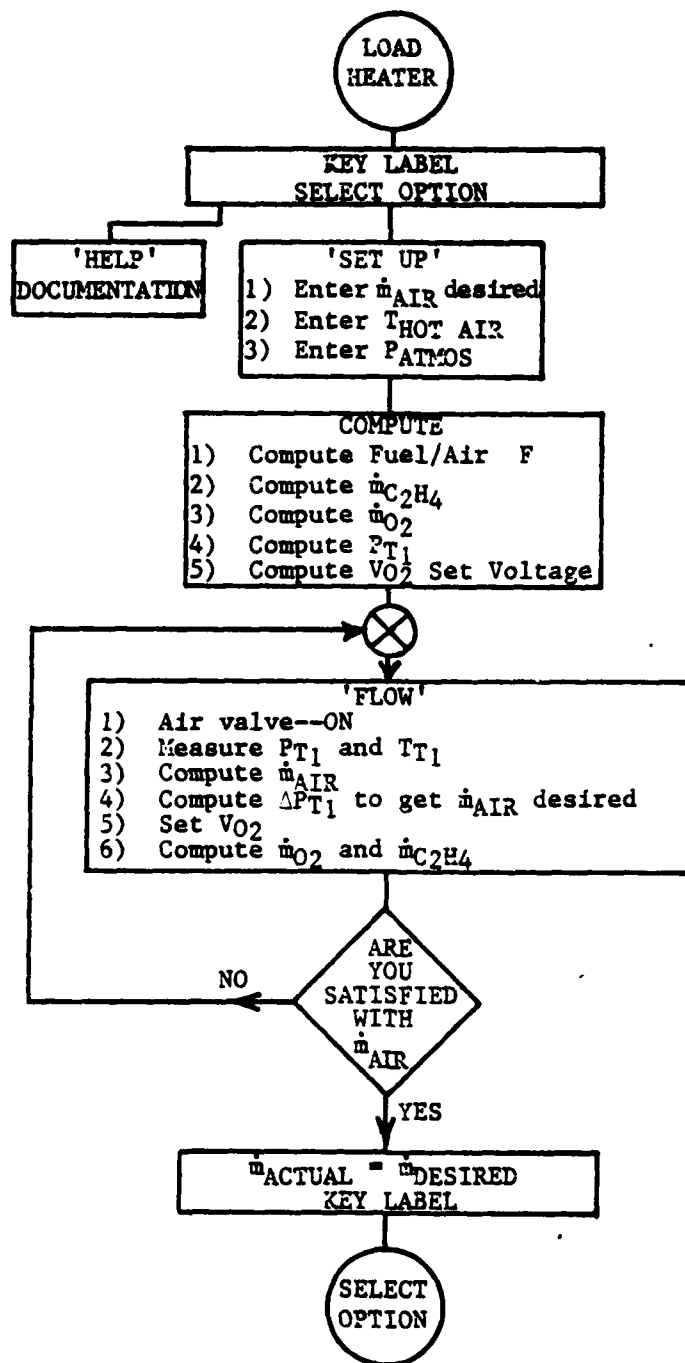


Figure 14. HEATER Flow Chart--Part One

The volume flow rates of oxygen and ethylene in SCFM are:

$$\dot{Q}_{O_2} = 734.89 \cdot \dot{m}_{O_2}$$

$$\dot{Q}_{C_2H_4} = 839.87 \cdot \dot{m}_{C_2H_4}$$

thus

$$\dot{Q}_{O_2} = 3\dot{Q}_{C_2H_4}$$

where  $\dot{Q}$  is the volume flow rate. The oxygen and ethylene flowmeters produce 0-5 Volt DC signals linear with volume flow rate (0-20 SCFM for oxygen and 0-6.5 SCFM for ethylene). The required oxygen and ethylene set voltages are computed from

$$V_{O_2} = 183723 \cdot \dot{m}_{O_2} \text{ (lbm/sec) (millivolts)}$$

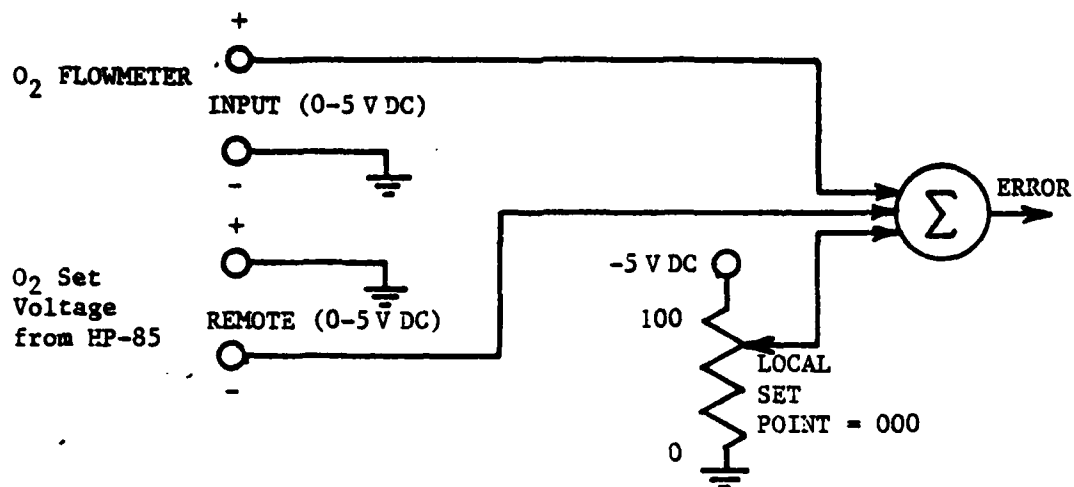
$$V_{C_2H_4} = 646054 \cdot \dot{m}_{C_2H_4} \text{ (lbm/sec) (millivolts)}$$

$V_{O_2}$  is generated by the dual channel digital to analog (D/A) converter card in the 3497A and sent to the REMOTE terminals of the oxygen flow controller (Fig. 13). This flow controller is set to the 'BIAS' mode of operation with the Local Set Point (LSP) control set to zero.

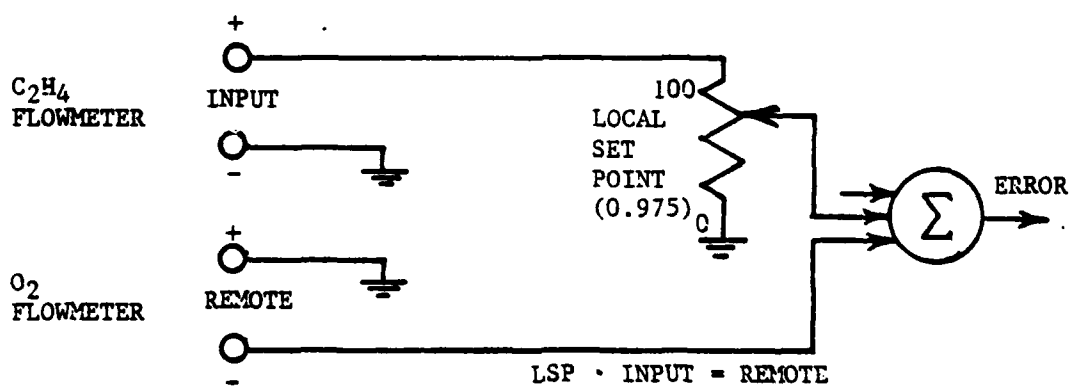
In this position (Fig. 15a) the input stages of the flow controller sum the three voltages and generate an error signal:

$$\text{ERROR} = \text{INPUT} - \text{LSP} - \text{REMOTE}$$

This signal drives the flow control until the error signal is equal to zero, which occurs when the desired oxygen flow rate



(a) Bias Mode



(b) Ratio Mode

Figure 15. Flow Controller Input Diagram



is achieved. With the LSP set to 000, the oxygen set voltage from the D/A converter acts as a remote set point to control the desired flow rate. The upper section of figure 13 shows the interconnections of the second flow controller, the ethylene flowmeter, and the oxygen flowmeter in the RATIO mode of operation. In this mode, the flow controller acts to provide the proper ratio of ethylene to oxygen under all conditions by controlling the ethylene volume flow rate to maintain a 1:3 ratio. Thus, the computer controls the oxygen flow rate which in turn controls the ethylene flow rate.

Figure 15b shows the flow controller input circuit in the 1-5 RATIO mode. In this case, the REMOTE (OXYGEN) signal is equal to the product of the Local Set Point (LSP) and the INPUT (ETHYLENE) signal.

$$\text{LSP} \cdot \text{INPUT} = \text{REMOTE}$$

However, the input (ethylene) and remote (oxygen) flow capacities are different. Dividing by the full scale flow capacities in SCFM normalizes the equation.

$$\text{LSP} \cdot \left( \frac{\text{INPUT}}{6.5} \right) = \left( \frac{\text{REMOTE}}{20} \right)$$

REMOTE = Oxygen volume flow rate

INPUT = Ethylene volume flow rate

Then,

$$\frac{\text{INPUT}}{\text{REMOTE}} = \left( \frac{6.5}{20} \right) \left( \frac{1}{\text{LSP}} \right) = \frac{1}{3}$$

Thus, LSP = 0.975.

For example, if the desired oxygen flow rate is 3.5 SCFM or 0.00476 lbm/sec, then the OXYGEN set voltage is

$$V_{O_2} = 3.5 \text{ SCFM} \frac{5 \text{ Volts}}{20 \text{ SCFM}} = 0.875 \text{ Volts}$$

The computer sends 0.875 volts to the remote terminals of the oxygen flow controller. The RATIO controller responds by driving the flow control valve until the ethylene flowmeter reads:

$$\text{INPUT} \cdot \text{LSP} = \text{REMOTE}$$

$$\text{INPUT} = \frac{0.875}{0.975} = 0.8974 \text{ VOLTS}$$

This corresponds to an ethylene volume flow rate of

$$\dot{Q}_{C_2H_4} = 0.8974 \text{ Volts} \frac{6.5 \text{ SCFM}}{5 \text{ Volts}}$$

$$\dot{Q}_{C_2H_4} = 1.166 \text{ SCFM}$$

which is 1/3 of the oxygen volume flow rate.

This completes the preliminary calculations and the system is now turned on to provide air flow without any heat addition. Thus, the operator selects the 'FLOW' option (Fig. 14) and the computer measures ambient pressure then opens the air valve, allowing air to flow to the heater while other components are maintained in the off position. High pressure air passes through a choked flow nozzle, where  $P_{T1}$  and  $T_{T1}$  are measured. Based on these measurements the actual mass flow rate is computed from:

$$\dot{m}_{AIR} = \frac{C_D P_{T1} A^* F_1}{\sqrt{\frac{R T_{T1}}{g_c}}} \quad (\text{lbm/sec})$$

where

$$F_1 = \sqrt{\gamma \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{\gamma-1}}}$$

$$\gamma = 1.4 \quad \text{AIR}$$

$$A^* = \frac{\pi d^{*2}}{4} \quad (\text{in}^2)$$

$$d^* = .235 \text{ (in) typical}$$

$$C_D = 0.97, \text{ discharge coef.}$$

$$R = 53.3 \frac{\text{ft-lbF}}{\text{lbm}^\circ\text{R}}$$

$$T_{T1} = \text{measured temperature, } ^\circ\text{R}$$

$$P_{T1} = \text{measured pressure, PSIA}$$

$$g_c = 32.2 \frac{\text{lbF ft}}{\text{lbm sec}^2}$$

The actual mass flow rate of air is displayed and an updated oxygen set voltage is computed and set. The required pressure correction  $\Delta P_{T1}$  is computed to meet the desired mass flow rate.

The operator may then accept the flow conditions and proceed to another program segment. If he accepts these flow conditions, the actual mass flow rate of air is set equal to the desired mass flow rate. If he is not satisfied with existing flow conditions,  $P_{T1}$  is adjusted manually by

applying the recommended  $\Delta P_{T_1}$ . The 'FLOW' option is automatically executed again until the desired accuracy is attained.

Once the desired mass flow rate of air is obtained, the 'START' option is executed. Figure 16 shows a flow chart of this program segment. This routine first closes all valves and measures  $P_{T_1}$  which represents ambient pressure under no flow conditions. The proper oxygen set voltage is set according to the latest flow calculations. The computer then turns on the high pressure air flow, energizes the igniter system, and turns on the ethylene and oxygen flow to the heater section. The output hot air temperature is monitored by a thermocouple and measured by the computer at 0.5 second intervals during the start up sequence, beginning 3 seconds after ignition. The igniter is turned off after 5 seconds of operation unless secured earlier by manual control.

During heater start up a typical temperature-time trace would be as shown in figure 17.

Temperature is closely monitored during the start sequence and igniter shutdown is executed:

- 1) when  $T_{HOT\ AIR}$  reaches  $700^\circ R$  (if not previously secured by the 5 second timer)
- 2) if  $T_{HOT\ AIR}$  falls by  $50^\circ R$  in any 5 second interval then HEATER shutdown is called to close the OXYGEN and ETHYLENE valves, close igniter valves, set  $O_2$  set voltage = 0 and close the high pressure air valve.

When  $T_{HOT\ AIR}$  reaches  $T_{DESIRED} - 100^\circ$  the Heater Maintenance routine is called, terminating the start sequence. The

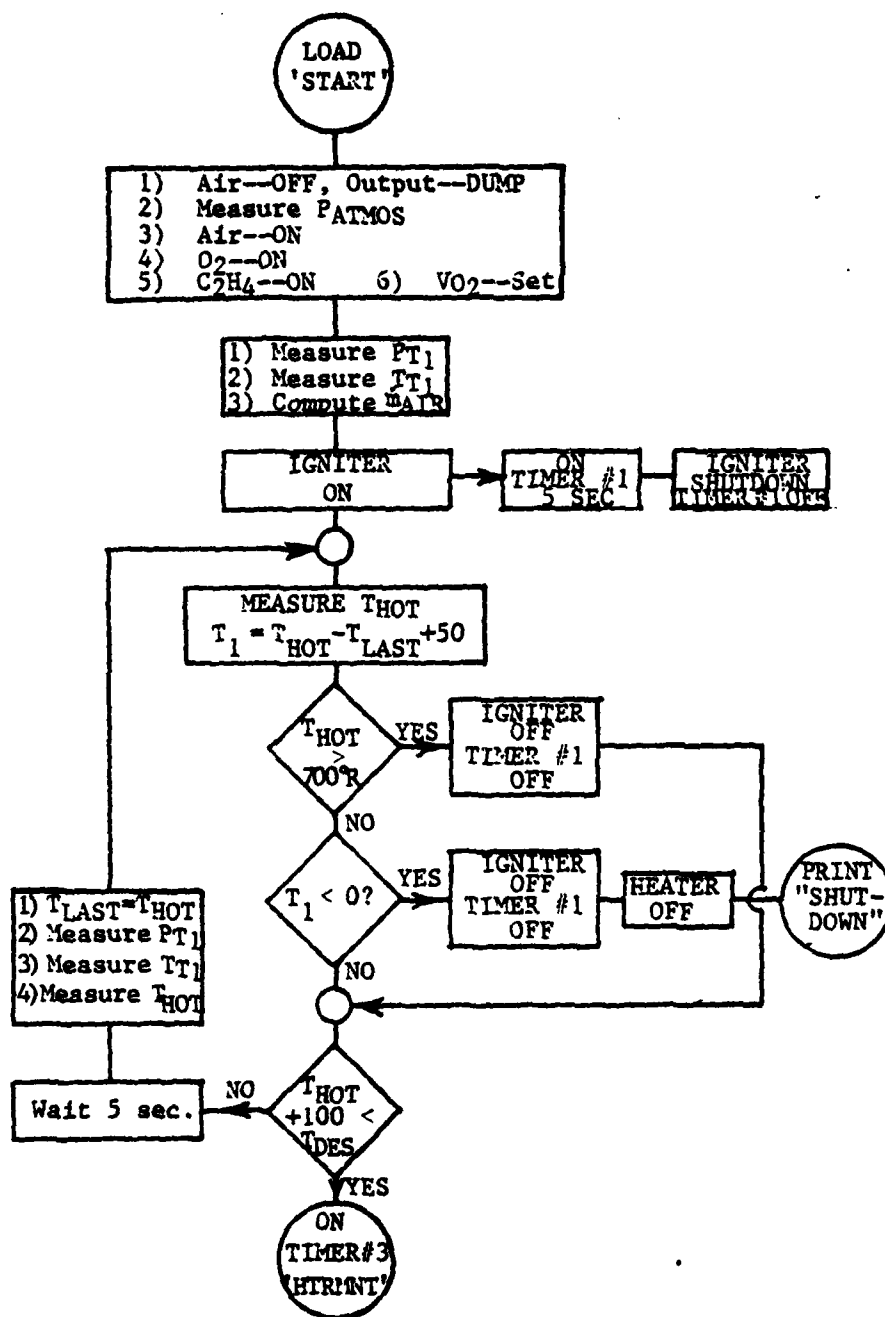


Figure 16. HEATER Flow Chart--Part Two

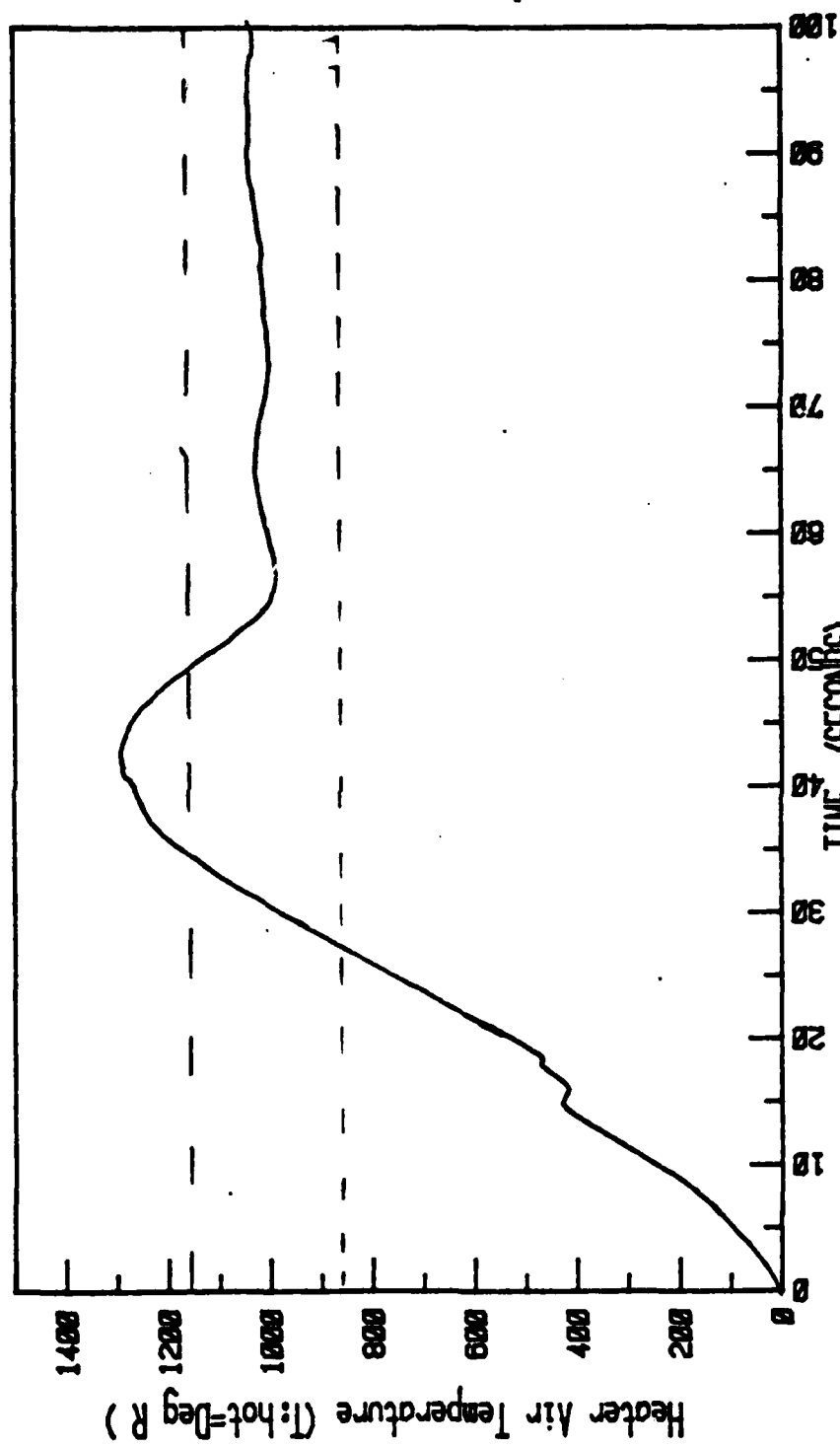


Fig. #17 Typical Temperature vs. Time Trace.

Heater Maintenance Program is assigned to timer #3 and set to automatically execute every 20 seconds, while another project program segment is run.

Figure 18 shows the flow chart for the Heater Maintenance Program segment (HTRMNT), which is assigned to Timer #3 to interrupt the computer at 20 second intervals to control the heater output temperature. On interruption, the computer measures the output air temperature and compares it to the desired air temperature. If the difference is greater than  $200^{\circ}\text{R}$  the heater shutdown program is called and secures the heater entirely. If the difference is less than  $100^{\circ}\text{R}$  the computer records the air temperature and returns to whatever routine was operating prior to the interrupt. However, if the difference between actual temperature and desired temperature is over  $100^{\circ}$  and less than  $200^{\circ}\text{R}$  the sign of the error is determined and the fuel air ratio is adjusted to compensate for the temperature deviation. Oxygen and ethylene flow rates are updated and a new oxygen set voltage is sent to the oxygen flow controller to effect a change in the output temperature. The output temperature is then recorded and a return from interrupt is executed.

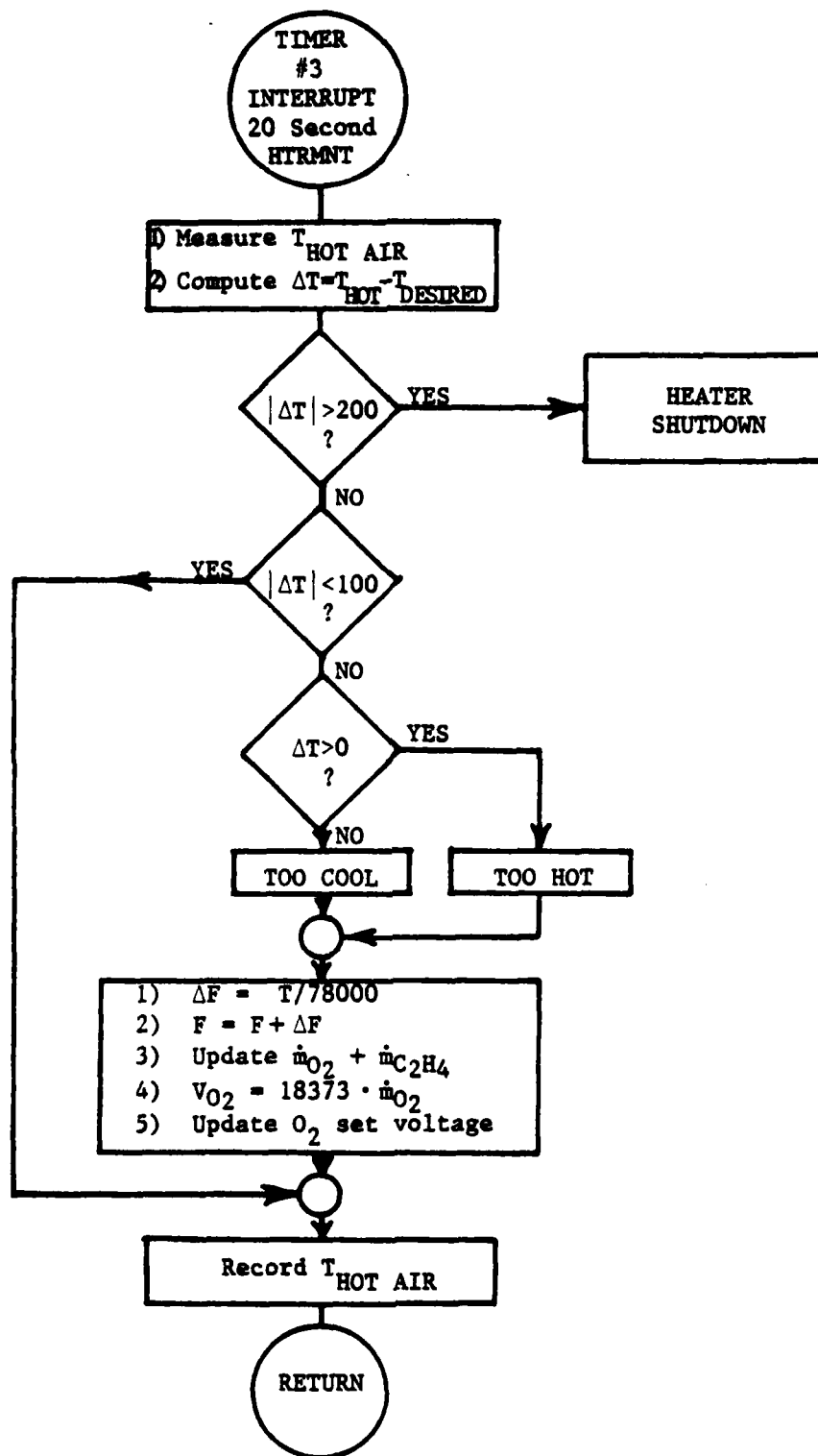


Figure 18. HEATER Flow Chart--Part Three



## V. SOLID FUEL RAMJET

The Solid Fuel Ramjet (SFRJ) test facility at the combustion laboratory has been constructed to facilitate the measurement of performance as affected by design and operating variables. Figure 19 presents a schematic of the SFRJ motor which is mounted on a thrust stand. Figure 20 presents a schematic of the air supply system. Air flow is directed to the head-end and sometimes also to the aft mixing chamber (bypass-air) of the combustor. In general, a test sequence is as follows: air flow rate(s) are turned on, the igniter is actuated, a small amount of ethylene is mixed with the head-end air flow, the motor ignites, the igniter and ethylene flows are terminated, the motor runs for 10-45 seconds duration, air flow is terminated and nitrogen gas is flowed through the fuel grain for five seconds to ensure extinguishment of the flame. During the test it is important to measure air flow rates, inlet air temperature, head-end, and mixing chamber pressures. Postfire data collected include fuel grain weight loss which is needed to calculate the average fuel flow rate and average fuel regression rate.

Temperature rise combustion efficiency for the test is determined from

$$\eta_{\Delta T} = \frac{T_{\text{exp}} - T_{\text{air}}}{T_{\text{th}} - T_{\text{air}}}$$

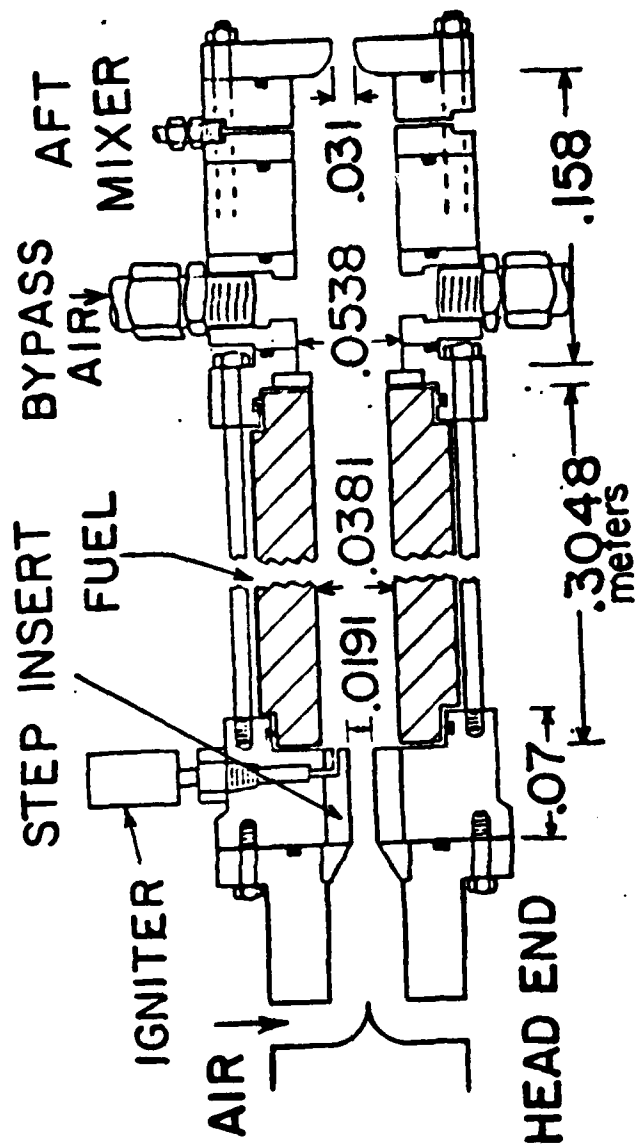


Figure 19. Solid Fuel Ramjet Motor

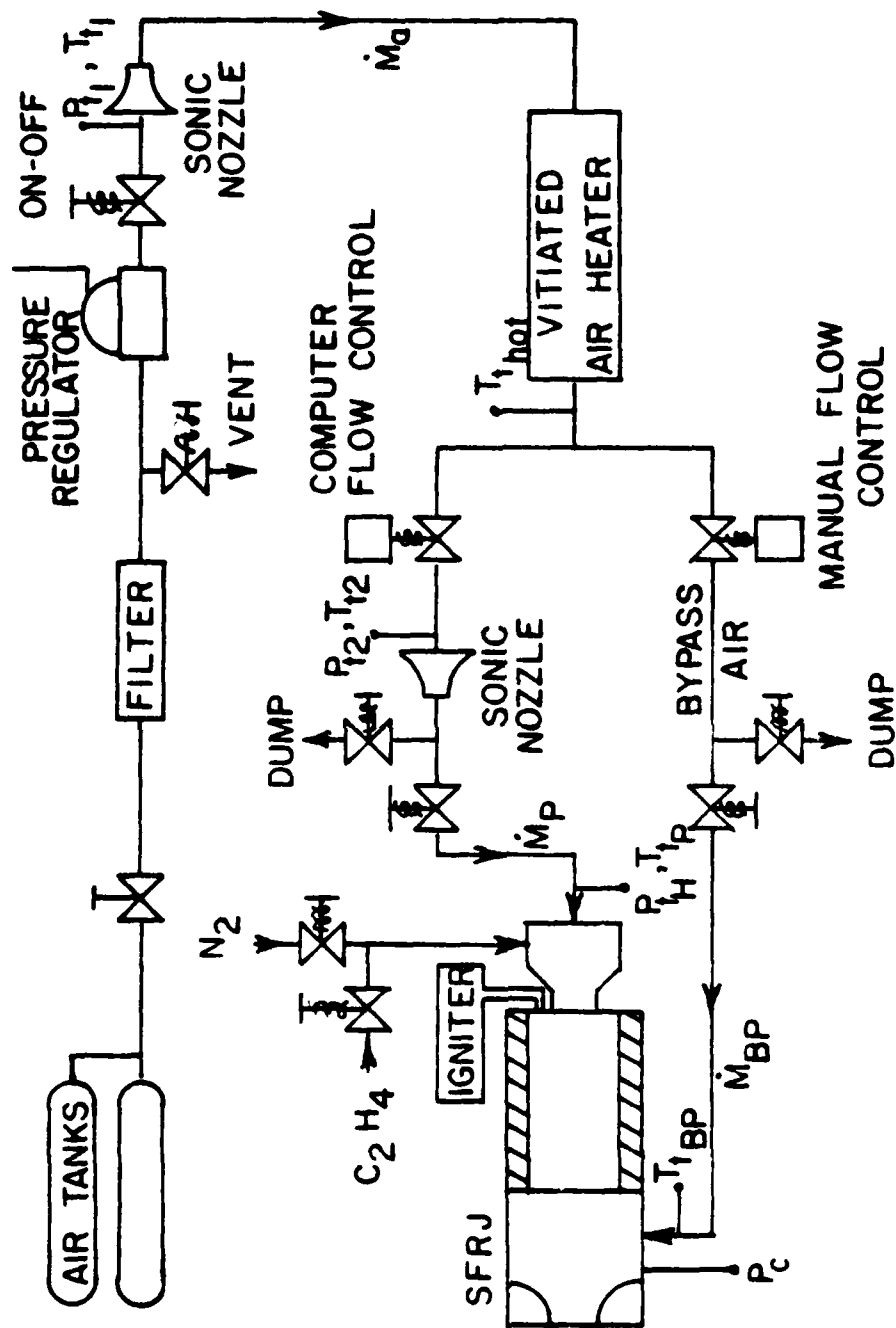


Figure 20. Solid Fuel Ramjet Functional Block Diagram

where  $T_{t_{air}}$  is the measured inlet air stagnation temperature,  $T_{t_{th}}$  is the theoretical combustion temperature determined from adiabatic, equilibrium combustion calculations using the measured fuel-air ratio, inlet air temperature and average chamber pressure.  $T_{t_{exp}}$  is the experimentally determined combustion temperature. The latter is calculated from conservation of mass, using gas properties determined from the equilibrium calculations. Thus,

$$T_{t_{exp}} = \left[ \frac{C_D \bar{P}_C A_{th}}{\dot{m}_t} \right]^2 \left[ \frac{g_c \gamma}{R} \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{\gamma-1}} \right]$$

where  $\dot{m}_T = \dot{m}_{air} + \dot{m}_{fuel}$

$A_{th}$  = nozzle throat area

$\bar{P}_C$  = average chamber stagnation pressure

$C_D$  = nozzle discharge coefficient

Average fuel regression rate is calculated based upon fuel weight loss during the burn. Thus,

$$\bar{d}_f = \sqrt{\frac{4\Delta W}{\pi L \rho} + \bar{d}_i^2}$$

and

$$\bar{r} = \frac{\bar{d}_f - \bar{d}_i}{2t_b}$$

where  $\Delta W$  = fuel weight loss

$L$  = fuel grain length

$\rho$  = fuel density

$\bar{d}_f$  = final average fuel internal diameter

$t_b$  = burn time

$\bar{F}$  = average fuel regression rate

The average chamber pressure ( $\bar{P}_C$ ) used to determine  $T_{texp}$  is obtained from the pressure time trace recorded during the test. A typical trace is shown in figure 21.

The test control/data acquisition/data reduction program that performs the above experiment is described in this section.

Figure 22 depicts the flow chart for the Solid Fuel Ramjet 'SFRJ' option, which is assigned to special function key #3 on the HP-85. This option is executed after having loaded and run the 'HEATER' program (figure 14), completed the 'SETUP' option, and executed the 'FLOW' option to set up the proper flow rates of air, oxygen, and ethylene. If the vitiated air heater is to be used, the 'START' option (figure 16) is executed to bring the heater up to stable operating temperature. Once the air temperature and total air flow rate ( $\dot{m}_A$ ) are within desired limits of the required values, the heater maintenance 'HTRMNT' (figure 18) is automatically set to interrupt the computer at 10 second intervals to check the operation of the heater.

Once the 'SFRJ' key is pressed, the operation of the Solid Fuel Ramjet is initiated. Both air flow control valves are initially opened to approximately the 50% position.

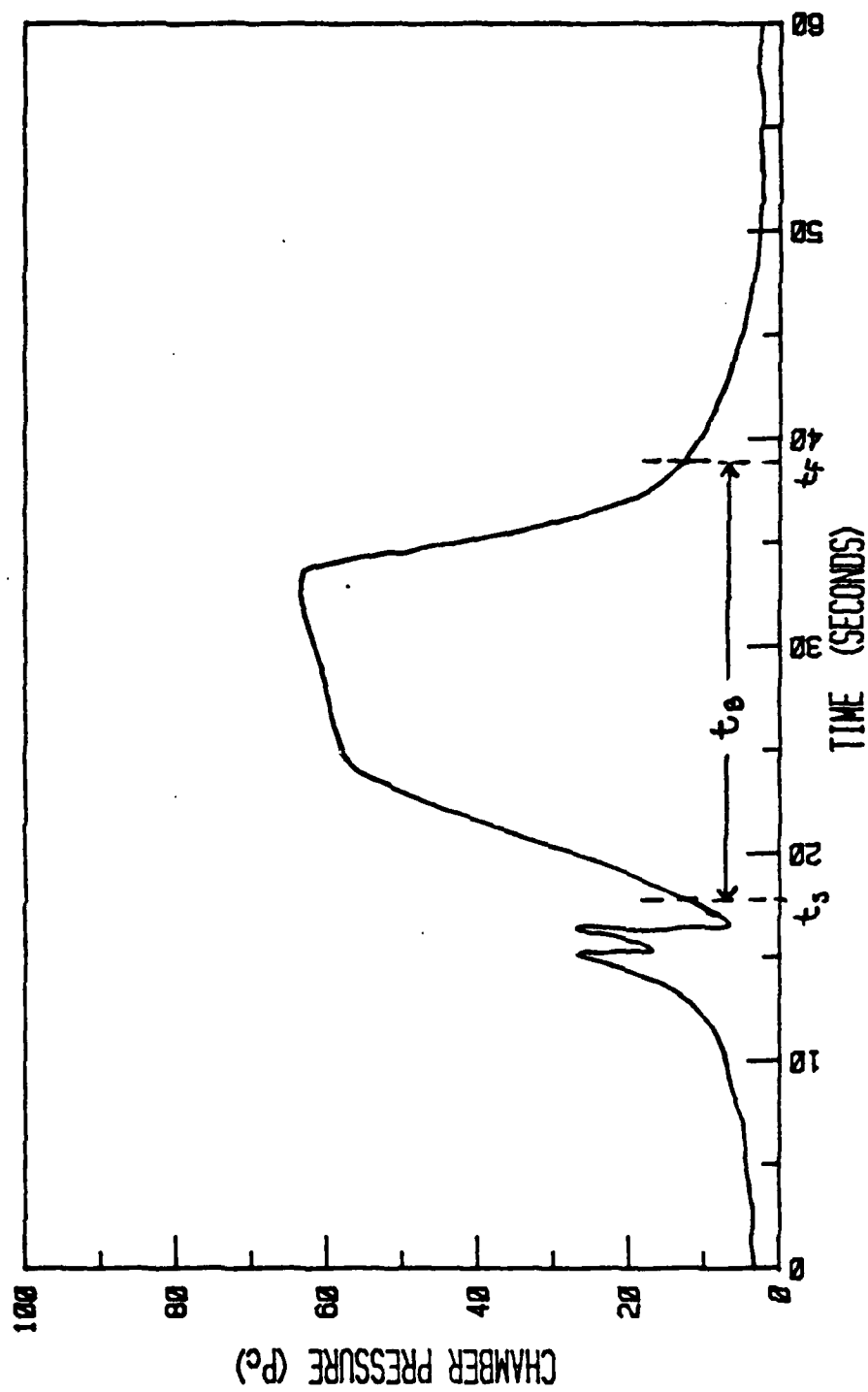


Fig. #21 Typical Pressure vs. Time Trace.

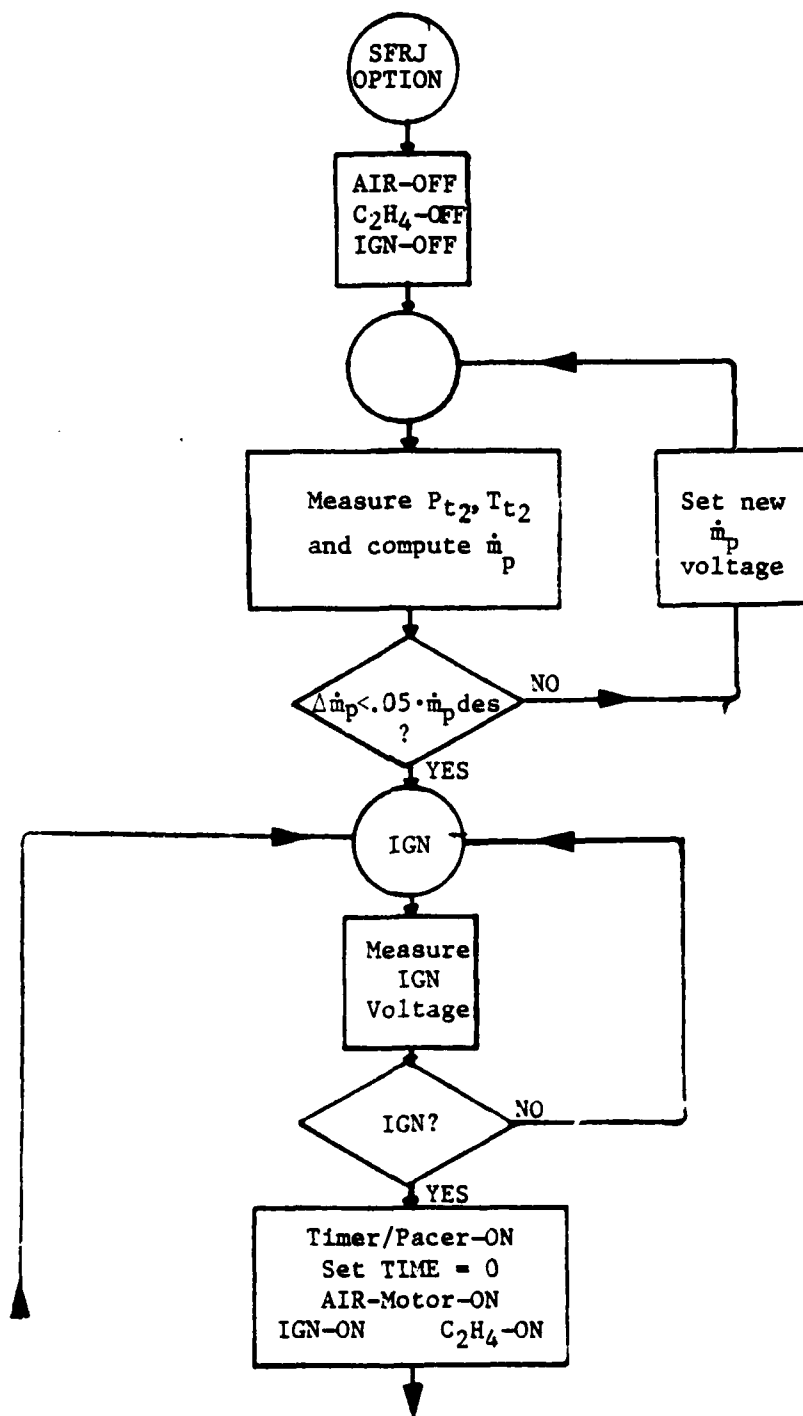


Figure 22. Solid Fuel Ramjet Flow Chart

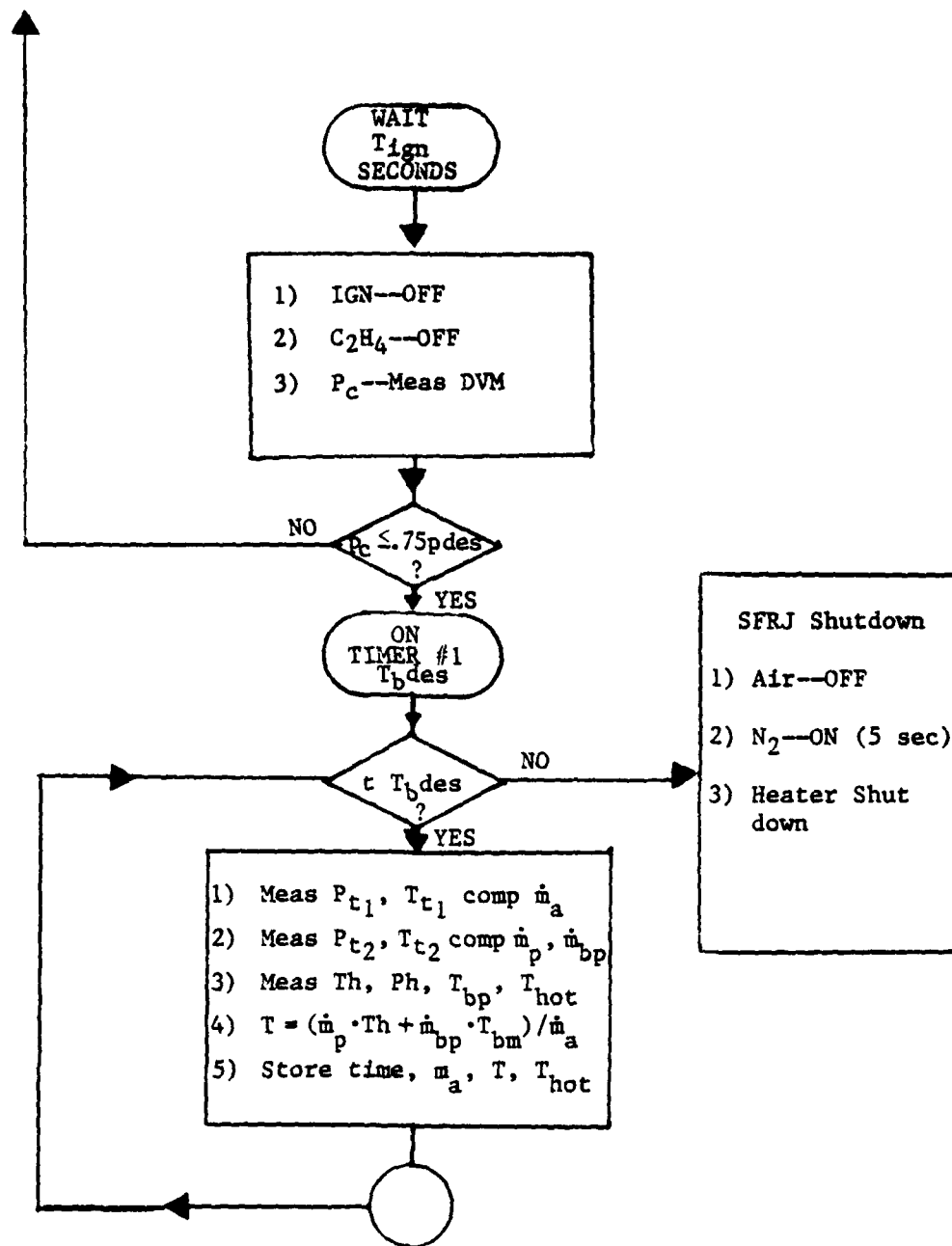


Figure 22 (Continued)



Initially, heater output air is routed via primary and bypass air lines to air dump valves, which are held in the dump position, venting heater air to atmosphere. The SFRJ igniter and the ethylene valves are also maintained off at this time.

The primary valve position is then adjusted by the computer until the primary air flow rate ( $\dot{m}_p$ ) is within 5% of the desired value. The computer programs the 6942A, TIMER/PACER, A/D converter, and memory cards to read the SFRJ motor chamber pressure ( $P_C$ ) transducer output voltage continuously for 60 seconds after being externally triggered. The reading rate is fixed at approximately 16 readings per second.

When the 6942 is programmed the SFRJ manual ignition switch is enabled by the computer which then monitors this switch until it detects closure. Once the switch is closed and sensed, the Timer/Pacer card is triggered and the computer timer is set to zero. Heater air is then directed into the SFRJ motor, the igniter is turned on, and the  $C_2H_4$  is turned on.

The computer waits a preset time in seconds ( $T_{IGN}$ ) before shutting off the igniter circuit and the  $C_2H_4$  valve. During the start sequence the 3456A digital voltmeter is set to monitor chamber pressure ( $P_C$ ). The chamber pressure is measured and compared to the desired steady state value. If this pressure exceeds .75 of the desired value by the end of ignition the computer proceeds to a measurement sequence of several pressures, temperatures, and flow rates until the

desired burn time in seconds expires. However, if the pressure is less than .75 of the desired value the program directs the user back to attempt another ignition sequence.

The automatic measurement sequence proceeds from the point where the pressure exceeds .75  $P_C$  desired as (refer to figure 21):

a)  $P_{T1}$ ,  $T_{T1}$  are measured

$$b) \dot{m}_{air} = \frac{P_{T1} A C_D F_1}{Q}$$

$$\text{where } C_D = .97$$

$$A = \pi d^2 / 4$$

$$d = .235$$

$$F_1 = \sqrt{\gamma \left( \frac{2}{\gamma+1} \right)^{\frac{\gamma+1}{\gamma-1}}}$$

$$\gamma = 1.4$$

$$Q = \sqrt{\frac{R T_{T1}}{g_C}}$$

c)  $P_{T2}$ ,  $T_{T2}$  measured at primary air orifice

$$d) \dot{m}_P = \frac{P_{T2} A_2 C_D F_1}{Q}$$

$$\text{where } Q = \sqrt{\frac{R T_{T2}}{g_C}}$$

e)  $V_{m_P}$  is set to obtain desired  $\dot{m}_P$

$$f) \dot{m}_{BYPASS} = \dot{m}_A - \dot{m}_{PRIMARY}$$

$$\dot{m}_{BYPASS} = 0 \text{ if no bypass selected}$$

g)  $T_{HOT AIR}$  measured

h)  $T_{BP}$  measured

i) SFRJ head pressure and temperature measured  $P_H$ ,  $T_H$

j) 
$$\bar{T} = \frac{\dot{m}_P T_H + \dot{m}_{BP} T_{BP}}{\dot{m}_{air}}$$

k) Values of time,  $\dot{m}_{air}$ ,  $\bar{T}$ , and  $T_{HOT}$  are stored in an array for later use in reduction of data.

The above measurements proceed for a total of 100 readings at a rate of approximately 1.5 per second.

Both the SFRJ and the heater are shut down automatically when timer #1 expires at ( $t_b$ ) seconds after successful ignition.

Once the measurement sequence completes and the shutdown sequence is completed the computer then waits until the multi-programmer memory board signals completion of its storage operation.

During the operation of the SFRJ option, special function key #4 is assigned to the SFRJ shutdown routine. This program is automatically executed  $t_b$  seconds after ignition, however, it can be invoked at any time by the operator and when called performs the following steps:

- a) Air valve to dump position
- b) Nitrogen purge on for 5 seconds
- c) Heater shutdown sequence.

After all timed events have completed the computer automatically loads and executes 'SFRJ2', which is the data

reduction program for the Solid Fuel Ramjet experiment. Figure 23 shows the flowchart of the data reduction program.

A large quantity of measured data is automatically passed from the Heater program to the reduction program. The computer then prompts the user for other required input data, such as:

- a) fuel type HTPB/PMM
- b) final grain weight (grams)
- c) initial grain weight (grams)
- d) initial grain internal diameter (cm)
- e) final aft-end internal diameter (cm)
- f) grain length (cm)
- g) area of the exhaust nozzle throat (cm<sup>2</sup>)

With this data entered and stored, the computer then reads in the chamber pressure ( $P_C$ ) array, which is a 1000 element vector of transducer voltages. These voltages are subsequently converted to pressure (PSIA) by the formula

$$P_C(I) = K_1 (V(I) - V_0) + B_9$$

where  $K_1 = 79.434$

$V(I)$  = transducer voltage

$V_0$  = initial transducer voltage at zero psig

$B_9$  = atmospheric pressure

The computer then locates the maximum pressure reading and its location in the array. The computer then searches both forward and backward in time from the location of the

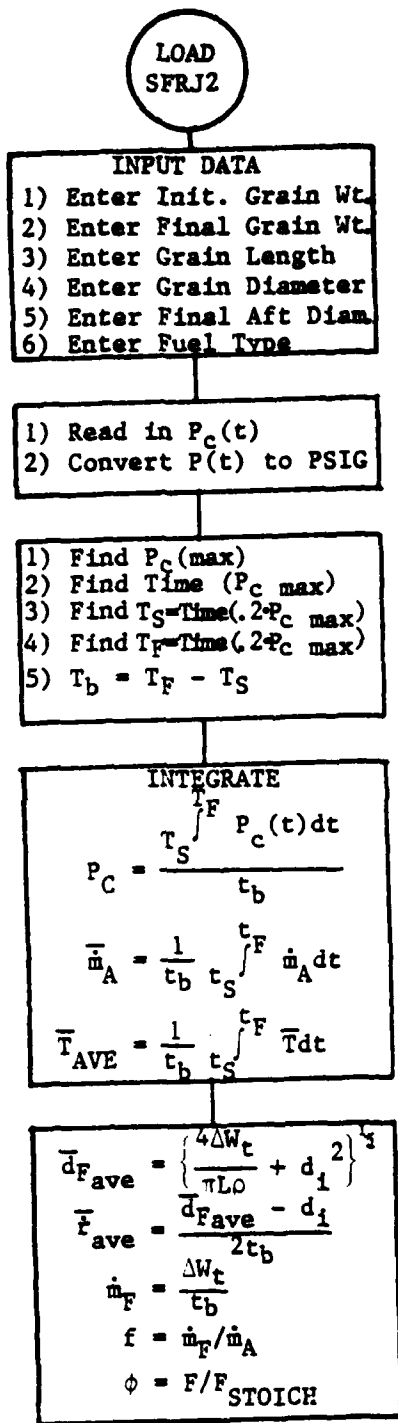


Figure 23. Solid Fuel Ramjet Reduction Flow Chart

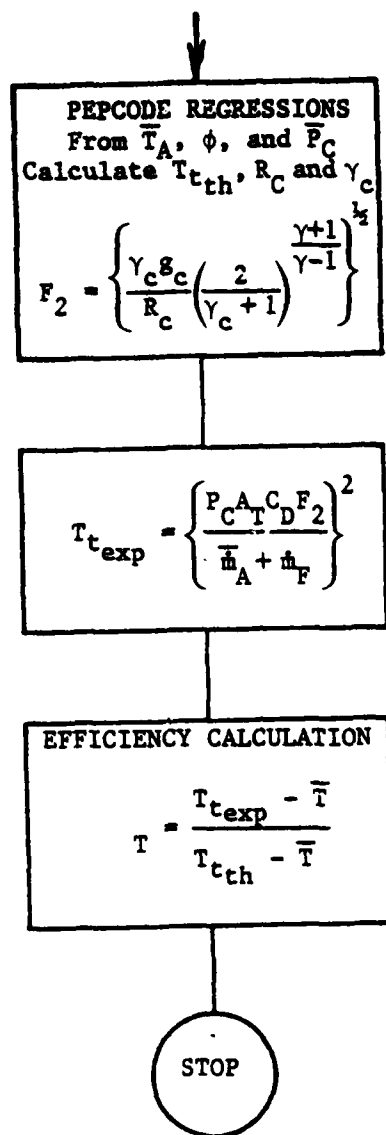


Figure 23 (Continued)

maximum pressure until it finds the time where pressure has dropped to 0.2 times the maximum pressure and records these locations as  $t_{\text{start}}$  and  $t_{\text{finish}}$ . The effective final burn time is  $t_{\text{BF}} = t_F - t_S$ . The computer then performs a numerical integration of the pressure time trace from  $t_S$  to  $t_F$  and divides the result by  $t_{\text{BF}}$  to give  $\bar{P}_C$ , the average pressure.

$$\bar{P}_C = \frac{\int_{t_S}^{t_F} P_C(t) dt}{t_{\text{BF}}}$$

Now that  $t_S$  and  $t_F$  are known, the computer can locate these times in the time column of the data array (100x3 matrix) and note the row numbers of  $I_S$  and  $I_F$ . The average air temperature  $\bar{T}_{\text{ave}}$  and flow rate  $\dot{m}_{\text{air}}$  are then computed between  $t_S$  and  $t_F$  by:

$$\dot{m}_{\text{air}} = \frac{\sum_{i=I_S}^{I_F} \dot{m}_A}{(I_F - I_S)}$$

$$\bar{T}_{\text{av}} = \frac{\sum_{i=I_S}^{I_F} \bar{T}}{(I_F - I_S)}$$

Data reduction can now proceed as follows:

$$\Delta W_t = \text{Initial } W_t - \text{Final } W_t$$

$$d_F = \sqrt{\frac{4 \Delta W_t}{\pi \rho_p L} + d_i^2}$$

where  $\rho_p$  = Fuel propellant density (gms/cm<sup>3</sup>)

$L$  = length (cm)

$d_i$  = initial diameter (cm).

The average burn rate is then

$$\dot{r}_{ave} = \frac{\bar{d}_f - d_i}{2t_{BF}} .$$

The equivalent fuel flow rate

$$\dot{m}_F = \frac{\Delta W_t}{t_{BF}} .$$

Thus, fuel/air and equivalence ratios are

$$f = \frac{\dot{m}_F}{\dot{m}_A}$$

and

$$\phi = \frac{f}{f_{STOICH}}$$

Then with  $\bar{T}$ ,  $\phi$ , and the type of fuel burned, the theoretical values of  $T_{t_{th}}$ ,  $R_C$ , and  $\gamma_C$  are computed from a polynomial regression obtained from the PEPCODE [Ref. 5] computer program at the Naval Postgraduate School computer center. The effect of  $\bar{P}_C$  on  $T_{t_{th}}$  is negligible for nominal variations (40-60psia). However,  $\bar{P}_C$  effects can be readily incorporated if desired. These polynomial equations are given in Appendix B.



Once the values of  $T_{tth}$ ,  $R_C$ , and  $\gamma_C$  are known then:

$$F_2 = \left\{ \frac{\gamma_C}{R_C} g_C \left( \frac{2}{\gamma_C + 1} \right)^{\frac{\gamma_C + 1}{\gamma_C - 1}} \right\}^{\frac{1}{2}}$$

and the experimental value of chamber stagnation temperature  $T_{texp}$  is determined from

$$T_{texp} = \left( \frac{P_C A_T C_D F_2}{(\dot{m}_{ave} + \dot{m}_F)} \right)^2$$

where  $A_T$  = throat area

$$C_D = .97$$

Finally, the efficiency is computed

$$\eta_{AT} = \frac{T_{texp} - \bar{T}}{T_{tth} - \bar{T}}$$

Hard copy printouts of all data is then provided by the system printer.

APPENDIX A  
LIST OF HP-IB ADDRESSES

1	CRT (internal)
2	Printer (internal)
701	2631B Line Printer
705	7225 Plotter
709	3497A Data Acquisition/Control Unit
721	HP-85 Controller
722	3456A High Accuracy Digital Voltmeter
723	6942A Multiprogrammer
724	3437A High Speed Digital Voltmeter
	HG-78 Scanivalve Interface #1
	HG-78 Scanivalve Interface #2
":D700"	Disc Drive #0
":D701"	Disc Drive #1
":T"	Internal Tape Drive

# APPENDIX B

## PEPCODE REGRESSION EQUATIONS FOR HTPB AND PMM

$$\text{HTPB} = \text{Fuel Type} \quad f_{\text{STOICH}} = .073 \quad \rho_P = .0332 \text{ #m/in}^3$$

$$\phi = \frac{f}{f_{\text{STOICH}}} \quad \bar{P}_C = 40-60 \text{ psia}$$

$$\begin{aligned} T_{t_{\text{TH}}} = & -933.3 + 4893\phi + 203\phi^2 - 899\phi^3 - 205.9\phi^6 + 1.1925\bar{T}_A \\ & + 1.014(10^{-4})\bar{T}_A^2 - 1.84(10^{-8})\bar{T}_A^3 - 1.138\bar{T}_A + .3864\bar{T}_A\phi^2 \\ & - 7.67(10^{-5})\bar{T}_A^2\phi \end{aligned}$$

$$\begin{aligned} \gamma_C = & 1.40162 - .27723\phi + .1483\phi^2 - .02448\phi^3 + .00523\phi^6 \\ & - 4.994(10^{-5})\bar{T}_A + 4.255(10^{-9})\bar{T}_A^2 - 2.36(10^{-13})\bar{T}_A^3 \\ & + 7.7585(10^{-5})\bar{T}_A\phi - 3.1138(10^{-5})\bar{T}_A\phi^2 - 1.885(10^{-9})\bar{T}_A^2\phi \end{aligned}$$

$$\begin{aligned} R_C = & 52.966 + 3.516\phi - 9.55\phi^2 + 5.71\phi^3 + .2739\phi^6 \\ & - 8.08(10^{-4})\bar{T}_A + 1.36(10^{-7})\bar{T}_A^2 - 5.99(10^{-11})\bar{T}_A^3 \\ & + 1.0208(10^{-3})\bar{T}_A\phi - 1.872(10^{-4})\bar{T}_A\phi^2 + 2.185(10^{-7})\bar{T}_A^2\phi \end{aligned}$$

PMM = Fuel Type

$$f_{\text{STOICH}} = 0.12$$

$$\rho_P = .0426 \text{ #m/in}^3$$

$$\bar{P}_C = 40-60 \text{ psia}$$

$$T_{t_{\text{TH}}} = 1642 - 5902\phi + 14688\phi^2 - 7478\phi^3 + 4.05\bar{T}_A\phi \\ - .18\bar{T}_A - 4.68\bar{T}_A\phi^2 + 1.28\bar{T}_A\phi^4 - 3.259(10^{-5})\bar{T}_A^2\phi^2$$

$$\gamma_C = 1.34 - .0265\phi - 9.126(10^{-6})\bar{T}_A - .193\phi^2 + .1329\phi^3 \\ - 4.205(10^{-5})\bar{T}_A\phi + 7.429(10^{-5})\bar{T}_A\phi^2 - 2.72(10^{-5})\bar{T}_A\phi^4 \\ + 2.09(10^{-9})\bar{T}_A^2\phi^2$$

$$R_C = 47.1569 + \phi [27.54 + \phi \{2.9108 - \phi (41.242 - \phi [19.545 - 11.567\phi^3])\}] \\ + (10^{-6})\bar{T}_A [12403 - 3.2029(10^{-3})\bar{T}_A^2]$$

## APPENDIX C

### PROGRAM LISTINGS

```
10 ! HELP FOR HEATER
20 OPTION BASE 1
30 COM V(100,4),M9,N0$(1),P0,V9,B9
40 CRT IS 2
50 DISP "The HEATER program contains project control an
d"
60 DISP " DATA ACQUISITION and DATA REDUCTION programs
for the VITIATED AIR HEATER."
70 DISP "PRESS 'SET UP' KEY TO MAKE PRELIMINARY AIR FLO
W CALCULATIONS."
80 DISP "WHEN YOU ARE SATISFIED WITH YOUR CALCULATIONS
YOU CAN FLOW THE AIR SYSTEM TO CHECK."
90 DISP
100 DISP "PRESS 'FLOW' KEY TO COLD FLOW THE AIR TO MEAS
URE Pt1 AND Tt1 AND COMPUTE  $\dot{m}$  dot AIR."
110 DISP "IF YOU ARE NOT SATISFIED WITH Pt1 SETTING OR
ACTUAL AIR FLOW THEN 'FLOW' IS RUN AGAIN."
120 DISP "AFTER 'FLOW' IS EXECUTED THE 'START' OPTION K
EY IS PRESSED TO START HEATER SEQUENCE."
130 DISP "'START' BRINGS HEATER UP TO DESIRED TEMPERATU
RE ."
140 DISP "WHEN DESIRED TEMP IS ATTAINED THE 'HTRMNT' HE
ATER MAINT ROUTINE IS RUN EVERY 20 SECS."
150 DISP "THE HEATER IGNITER IS DE-ENERGIZED AFTER 8 SE
CONDS OF OPERATION OR WHEN 700 DEG IS "
160 DISP "REACHED , ALSO IF THE AIR TEMP DROPS BY 50 DE
G IN 5 SECONDS DURING START UP THE IGN"
170 DISP " IS SHUT OFF AND THE HEATER IS SECURED."
180 DISP "WHEN THE AIR TEMPERATURE IS WITHIN 150 DEGREE
S OF THAT DESIRED, THE HEATER MAINT "
190 DISP " ROUTINE IS CALLED. THIS PROGRAM EXECUTES EV
ERY 20 SECONDS UNTIL ANOTHER OPTION"
200 DISP " IS SELECTED, MEASURING AND RECORDING THE AIR
TEMP."
210 DISP " THE SOLID FUEL RAMJET OPTION KEY 'SFRJ' IS P
RESSED TO ENERGIZE THE SFRJ WITH OR "
220 DISP "WITHOUT THE HEATER IN OPERATION. THIS OPTION
RUNS FOR A PRESET TIME BEFORE SECURING"
230 DISP " 'SFRJ2' THE DATA REDUCTION PROGRAM IS AUTOMA
TICALLY CALLED AND EXECUTED AFTER 'SFRJ'"
240 CRT IS 1
250 CHAIN "HEATER"
260 END
```

```

10 ! HEATER
20 OPTION BASE 1
30 COM V(100,4),M9,N0$(11),P0,V9,B9
40 ON KEY# 1,"SET UP" GOSUB 150
50 ON KEY# 2,"FLOW" GOSUB 790
60 ON KEY# 3,"SFRJ" GOTO 2270
70 ON KEY# 7,"TJTC" GOSUB 1220
80 ON KEY# 5,"HELP" GOSUB 1240
90 ON KEY# 6,"START" GOSUB 1270
100 ON KEY# 4,"SHUTDOWN" GOSUB 2140
110 CLEAR @ KEY LABEL
120 DISP "SELECT OPTION"
130 GOTO 130
140 ! Initialize the constants as needed to do the preliminary
150 ! calculations for setting up the air heater.
160 DISP "WILL YOU BE RUNNING THE HEATER ONLY? (Y/N)"
170 INPUT Y$
180 IF Y$="N" THEN GOTO 2880
190 !
200 OUTPUT 709 ; "D04,4,5,6,7"
210 LET V9=280 ! STORAGE TANK VOLUME
220 G=1.4 ! AIR GAMMA
230 DISP "ENTER STORAGE TANK GAGE PRESSURE (PSIG)"
240 INPUT B8
250 LET C=.97 ! DISCHARGE COEF.
260 LET G1=32.2 ! GRAVITY
270 LET D=1.5 ! INCHES
280 D1=.235 ! Dstar choked venturi
290 LET R=53.3 ! GAS CONSTANT FOR AIR
300 CLEAR
310 DISP "ENTER DESIRED MASS FLOW RATE (#/SEC) M9"
320 INPUT M9
330 PRINT " FOR DESIRED MASS FLOW RATE OF ";M9;" #/SEC."
340 ! DISP "ENTER NOZZLE DIAMETER (D1=COLD AIR=D*)"
350 ! INPUT D1
360 DISP "ENTER COLD AIR TEMPERATURE (DEG=F) T1"
370 INPUT T1
380 LET T1=T1+460
390 DISP "ENTER DESIRED HOT AIR TEMPERATURE (DEG=R) T8"

400 INPUT T8
410 DISP "ENTER BAROMETRIC PRESSURE SETTING (INCHES HG)
(29.92=STANDARD SEA LEVEL)"
420 INPUT B9
430 B9=.4913*B9
440 ! B9 WILL BE USED TO CONVERT ABS PRESSURES TO GAGE"

450 ! NOW COMPUTE VISCOSITY FOR LATER USE"
460 LET U=.0000000229*T8^1.5/(T8+198.6)

```

```

470 !
480 ! COMPUTE FUEL AIR RATIO FROM PEPCODE EXCERT
490 LET F=(T8-550)/78000
500 ! This F was for air at approx. 70 degrees farenhei
    t.
510 ! compute ethylene flow rate
520 LET M8=F*M9 ! MDOT FUEL
530 M7=96/28*M8 ! OXYGEN FLOW RATE
540 V=183720*M7 ! OXYGEN SET VOLTAGE.
550 V$=VAL$(V)
560 OUTPUT 709 ; "A03,0,"&V$
570 CLEAR
580 DISP USING 590 ; M8;826.06*M8
590 IMAGE "SET ETHYLENE FLOW RATE=",1D.5D," #/SEC",5X,2
    D.3D," SCFM"
600 DISP USING 610 ; M7;722.58*M7
610 IMAGE "SET OXYGEN FLOW RATE=",1D.5D," #/SEC",5X,2D.
    3D," SCFM"
620 PRINT "OXYGEN VOLTAGE= ";V;" MILLIVOLTS"
630 LET A=PI/4*D1^2
640 LET F1=SQR(G*(2/(G+1))^((G+1)/(G-1)))
650 PRINT "F(GAMMA)=",F1
660 LET Q9=SQR(T1*R/G1)
670 LET P6=M9*Q9/(C*A*F1) ! PSIA
680 LET P5=P6-B9 ! PSIG
690 DISP USING 700 ; P5
700 IMAGE "SET PT TO ",6D," PSIG"
710 LET T5=(B8-P5*2)*V9*144/(R*T1*M9)
720 DISP USING 730 ; T5
730 IMAGE "RUN TIME IS ",5D.D," SECONDS"
740 COPY
750 CLEAR
760 DISP "SELECT OPTION"
770 KEY LABEL
780 RETURN
790 ! FLOW OPTION
800 OUTPUT 709 ; "D04,4,5,6,7" ! AIR VALVE CLOSED
810 CLEAR
820 WAIT 2000
830 ! THIS SEGMENT FLOWS THE SYSTEM COLD TO DETERMINE A
    CTUAL MASS FLOW RATE
840 OUTPUT 709 ; "AC5" ! MEASURE PT1
850 OUTPUT 722 ; "HSM002SW2Z0S01L1.1STIS0F1R1T3QX1"
860 GOSUB 2230
870 V0=V
880 PRINT "V0=",V0
890 OUTPUT 709 ; "DC4,6" ! AIR VALVE OPENS
900 WAIT 1000
910 OUTPUT 722 ; "HSM002SW2Z0S01L1.1STIS0F1R1T3QX1"
920 GOSUB 2230

```

```

930 PRINT "V=",V
940 P=79.434*(V-V0) ! VOLTS TO PSIG
950 PRINT "PT1=",P
960 OUTPUT 709 ;"AC6" ! MEASURE TT1
970 OUTPUT 722 ;"HSW2SM002Z0S01L1.1STIS0F1R1T1QX1"
980 GOSUB 2230
990 T=41575*V+536.6 ! VOLTS TO DEGREES R
1000 OUTPUT 709 ;"DO4,6" ! CLOSE AIR VALVE
1010 ! CONVERSIONS ON T AND P NEED TO BE DONE.
1020 Q9=SQR(R*T/G1)
1030 M=C*A*F1*(P+B9)/Q9 ! ACTUAL MA FLOW
1040 DISP "ACTUAL MASS FLOW RATE IS   =";M;" #m/sec."
1050 M8=F*M @ M7=96/28*M8
1060 V=183720*M7 ! OXYGEN SET VOLTAGE
1070 OUTPUT 709 ;"AO3,0,"&VAL$(V)
1080 P7=M9*Q9/(F1*C*A) ! PSIA

1090 P=P7-P-B9 ! PRESSURE INCREMENT
1100 PRINT " DELTA PT1=",P
1110 DISP USING 1120 ; P,M9
1120 IMAGE "CHANGE P+1 BY ",4D," PSIG TO ACHEIVE A Mdot
(AIR) OF ",D.5D," #mass/sec."
1130 DISP "ARE YOU SATISFIED WITH THE MASS FLOW RATE A
ND DOME PRESSURE SETTING? (Y/N)"
1140 INPUT Y$
1150 IF Y$="Y" THEN GOTO 1180
1160 T1=T ! P6=P7! SAVE LAST PT1 AND TT1
1170 GOTO 790
1180 DISP "SELECT OPTION"
1190 M9=M ! ACTUAL=DESIRED MDOT
1200 KEY LABEL
1210 RETURN
1220 BEEP 200,100
1230 RETURN
1240 ! HELP
1250 CHAIN "HELP"
1260 RETURN
1270 ! HEATER START UP ROUTINE
1280 OUTPUT 709 ;"DC4,6" ! AIR ON
1290 CLEAR
1300 OUTPUT 709 ;"AC5" ! P+1
1310 OUTPUT 722 ;"HSW2SM002Z0S01L1.1STIS0F1R1T1QX1"
1320 GOSUB 2230
1330 P=79.434*(V-V0) ! VOLTS TO PSIG
1340 OUTPUT 709 ;"AC6" ! T+1
1350 OUTPUT 722 ;"HSW2SM002Z0S01L1.1STIS0F1R1T1QX1"
1360 GOSUB 2230
1370 T=41575*V+536.6 ! T COLD
1380 Q9=SQR(R*T/G1)
1390 M=C*A*F1*(P+B9)/Q9 ! ACTUAL MDOT AIR

```



```

1400 M8=F*M @ M7=96/28*M8
1410 V=183720*M7 ! O2 SET VOLTS
1420 OUTPUT 709 ; "A03,0,"&VAL$(V)
1430 OUTPUT 709 ; "AC7" ! T hot
1440 OUTPUT 709 ; "DC4,7" ! IGNITER ON
1450 OUTPUT 709 ; "DC4,4,5" ! O2 & C2H4 ON
1460 ON TIMER# 1,8000 GOSUB 1670
1470 T3=T ! T LAST
1480 WAIT 5000
1490 OUTPUT 722 ; "HSW2SM002Z0S01L1.1STIS0F1R1T1QX1"
1500 GOSUB 2230
1510 T2=1002.3*V+457.53 ! Thot
1520 T1=T2-T3+50
1530 IF T2>700 THEN GOSUB 1720
1540 IF T1<0 THEN 1760
1550 PRINT "T:hot=",T2
1560 ! CHECK TO SEE IF HEATER IS WITHIN DESIRED LIMITS
1570 IF T2+150-T8>0 THEN 1840
1580 ! HEATER IS NOT YET NEAR OPERATING RANGE
1590 OUTPUT 709 ; "AC7"
1600 T3=T2 ! LAST T HOT
1610 WAIT 4000
1620 OUTPUT 722 ; "HSW2SM002Z0S01L1.1STIS0F1R1T1QX1"
1630 GOSUB 2230
1640 T2=1002.3*V+457.53 ! Thot
1650 T1=T2-T3+50
1660 GOTO 1540 ! READ T HOT AGAIN
1670 ! SHUT OFF IGNITER
1680 OUTPUT 709 ; "DO4,7"
1690 PRINT "IGNITER SHUT DOWN-5 SECS."
1700 OFF TIMER# 1
1710 RETURN
1720 OUTPUT 709 ; "DO4,7"
1730 OFF TIMER# 1
1740 DISP " T:HOT > 700 R IGNITER OFF"
1750 RETURN
1760 ! TEMP GRAD IS NEG TIME FOR SHUT DOWN
1770 OUTPUT 709 ; "DO4,7"
1780 OUTPUT 709 ; "DO4,4,5"
1790 OUTPUT 709 ; "A03,0,0"
1800 OUTPUT 709 ; "DO4,6" ! AIR OFF
1810 DISP " HEATER SHUTDOWN-NEG TEMP GRADIENT"
1820 OFF TIMER# 1
1830 STOP
1840 ! HEATER IS NEAR OPERATING POINT
1850 OFF TIMER# 1
1860 PRINT " HEY I'M CLOSE"
1870 ON TIMER# 3,10000 GOSUB 1940
1880 DISP "ENTER HEATER MAINT ROUTINE"
1890 CLEAR

```

```

1900 DISP "HEATER RUNNING"
1910 WAIT 500
1920 KEY LABEL
1930 GOTO 1890
1940 ! HEATER MAINTENANCE
1950 OUTPUT 709 ; "AC7"
1960 OUTPUT 722 ; "HSM002SW2Z0S01L1FL0.01STIS0F1R1T1QX1"

1970 GOSUB 2230 ! TAKE READING
1980 T2=1002.3*V+457.53 ! Thot
1990 PRINT "T:hot:AIR=";T2
2000 T4=T8-T2 ! DELTA T:hot
2010 IF ABS(T4)>200 THEN GOTO 2140
2020 IF ABS(T4)<100 THEN 1940
2030 IF T4<0 THEN GOTO 2060
2040 DISP " NOT HOT ENOUGH "
2050 GOTO 2080
2060 DISP " TOO HOT "
2070 GOTO 2080
2080 F4=T4/78000
2090 F=F+F4 ! NEW FUEL AIR RATIO
2100 M8=F*M9 @ M7=96/28*M8
2110 V=183720*M7
2120 OUTPUT 709 ; "A03,0,"&VAL$(V)
2130 RETURN
2140 ! HEATER SHUTDOWN
2150 OUTPUT 709 ; "A03,0,0"
2160 OUTPUT 709 ; "D04,7,4,5"
2170 PRINT "HEATER SHUTDOWN"
2180 PRINT " LAST T:hot=";T2
2190 WAIT 5000
2200 OUTPUT 709 ; "D04,4,5,6,7"
2210 OFF TIMER# 3
2220 RETURN
2230 ! SRQ SERVICE ROUTINE
2240 STATUS 7,1 ; Z9
2250 ENTER 722 ; V
2260 ENABLE INTR 7;8 @ CLEAR 722 @ RETURN
2270 ! SOLID FUEL RAMJET OPTION
2280 OUTPUT 709 ; "D04,8,9,10,11,12,13" ! AIR DUMP
2290 OFF KEY# 4 @ ON KEY# 4, "SHUTDOWN" GOSUB 3050
2300 IF N0$="N" THEN 2330
2310 OUTPUT 709 ; "DC4,9,13"
2320 DIM O0$(90)
2330 O0$="WF,3.1,0,3.2,0,3.3,0T,SF,2,3,1,.001,12T,MI,2,
1000T,WF,3,999T,AC,3T,WF,4.2,1T"
2340 OUTPUT 723 ; O0$
2350 OUTPUT 723 ; "OP,4,.03ST"
2360 CLEAR 722 @ OUTPUT 722 ; "HSM002SW2Z0S01L1FL0.01STI
S0F1R1T3Q"

```

```

2370 OUTPUT 709 ; "DC4,14." @ DISP "READY FOR SFRJ IGNITI
ON"
2380 OUTPUT 709 ; "AC13" ! Pchamber
2390 OUTPUT 722 ; "X1" @ GOSUB 2230
2400 V9=V ! INITIAL Pc READING
2410 OUTPUT 709 ; "AC14" ! IGNITION
2420 OUTPUT 722 ; "X1" @ GOSUB 2230
2430 IF ABS(V)<3 THEN 2420
2440 ! BEGIN SFRJ START UP
2450 SETTIME 0,0
2460 OUTPUT 709 ; "DC4,8,11,12"
2470 WAIT 1000*T6
2480 OUTPUT 709 ; "DO4,12,11"
2490 OUTPUT 709 ; "AC13" ! Pchamber
2500 OUTPUT 722 ; "X1" @ GOSUB 2230
2510 IF V>.75*(P0/151.5) THEN 2540
2520 CLEAR
2530 DISP "NO IGNITION TRY AGAIN" @ GOTO 2420
2540 ! BEGIN MEASUREMENT SEQ.

2550 ON TIMER# 1,T6*1000 GOSUB 3050
2560 OUTPUT 722 ; "HSM0029W2Z0S01L1FL0.01STIS0F1R1T3Q"
2570 FOR J=1 TO 100
2580 OUTPUT 709 ; "AC5" @ OUTPUT 722 ; "X1" @ GOSUB 2230
2590 P=79.434*(V-V0) @ OUTPUT 709 ; "AC6" @ OUTPUT 722 ;
"X1" @ GOSUB 2230
2600 T=41575*V+536.6 @ V(J,1)=C*A*F1*(P+B9)/SQR(R*T/G1)

2610 OUTPUT 709 ; "AC12" @ OUTPUT 722 ; "X1" @ GOSUB 2230

2620 T3=41575*V+536.6 @ OUTPUT 709 ; "AC7" @ OUTPUT 722
; "X1" @ GOSUB 2230
2630 V(J,4)=1002.3*V+457.5 @ T2=V(J,4) ! T:hot
2640 OUTPUT 709 ; "AC8" @ OUTPUT 722 ; "X1" @ GOSUB 2230
2650 P=79.434*(V-V0) @ OUTPUT 709 ; "AC9" @ OUTPUT 722 ;
"X1" @ GOSUB 2230
2660 T=41575*V+536.6 @ M3=C*A*F1*(P+B9)/SQR(R*T/G1)
2670 M4=V(J,1)-M3 @ V(J,3)=TIME
2680 IF N0#="N" THEN M4=0
2690 OUTPUT 709 ; "AC11" @ OUTPUT 722 ; "X1" @ GOSUB 2230

2700 P4=79.434*(V-V0) @ OUTPUT 709 ; "AC10" @ OUTPUT 722
; "X1" @ GOSUB 2230
2710 T4=41575*V+536.6 @ V(J,2)=(M3*T4+M4*T3)/V(J,1) ! T
bar
2720 PRINT "J=";J,"TIME=";V(J,3)
2730 PRINT "Thead=";T4
2740 PRINT "Phead=";P4
2750 PRINT "T:hot=";V(J,4)
2760 PRINT "n:dot AIR=";V(J,1)

```

```

2770 PRINT "M:dot PRI=",M3
2780 PRINT "T;bypass=",T3
2790 PRINT "T:BAR=",V(J,2)
2800 NEXT J
2810 Q0=SPOLL(723) ! WAIT FOR MEM INTR
2820 IF Q0<>64 THEN 2810
2830 DISP "MULTIPROGRAMMER HAS P:chamber data "
2840 SEND 7 ; UNL MLA TALK 23 SCG 12
2850 ENTER 723 ; Q1@ DISP " SLOT#=";Q1
2860 OUTPUT 723 ; "DC,3T,WF,4.2,0T,OP,4,0T"
2870 CHAIN "SFRJ2"
2880 DISP "WILL YOU BE RUNNING THE SOLID FUEL RAMJET? (
Y/N)"
2890 INPUT Y$
2900 IF Y$="Y" THEN GOTO 2940
2910 CLEAR
2920 DISP "TURBOJET COMBUSTOR OPTION IS NOT AVAILABLE A
T THIS TIME. SELECT ANOTHER OPTION"
2930 GOTO 150
2940 ! SFRJ OPTIONS
2950 CLEAR
2960 DISP "ENTER DESIRED CHAMBER PRESSURE (PSIA)"
2970 INPUT P0
2980 DISP "ENTER THE DESIRED BURN TIME IN (SECONDS)"
2990 INPUT TS
3000 DISP "ENTER THE IGNITION TIME IN (SECONDS)"
3010 INPUT T6
3020 DISP "WILL THE BYPASS OPTION BE USED? (Y/N)"
3030 INPUT N0$
3040 GOTO 190
3050 ! SFRJ SHUTDOWN
3060 OUTPUT 709 ; "DO4,8,9,11,12,13"
3070 OUTPUT 709 ; "DC4,10" ! N2 PURGE ON
3080 WAIT 5000 @ OUTPUT 709 ; "DO4,10"
3090 GOSUB 2140 ! HEATER SHUTDOWN
3100 CLEAR @ DISP "SFRJ& HEATER SHUTDOWN " @ KEY LABEL
3110 RETURN

```

```

10 ! SFRJ2 DATA REDUCTION
20 OPTION BASE 1
30 COM V(100,4),M9,N0$(11),P0,V9,B9
40 SHORT P(1000)
50 GCLEAR
60 CLEAR
70 G1=32.174 ! gc
80 C=.97 ! DISCHARGE COEF.
90 DISP "SFRJ DATA REDUCTIONS"
100 DISP "ENTER INITIAL GRAIN WEIGHT=(GRAMS)"
110 INPUT W1
120 DISP "ENTER FINAL GRAIN WEIGHT=(GRAMS)"
130 INPUT W2
140 DISP "ENTER GRAIN LENGTH=(CM)"
150 INPUT L2
160 L2=L2/2.54
170 DISP "ENTER INITIAL GRAIN DIAMETER=(CM)"
180 INPUT D0
190 D0=D0/2.54
200 DISP "ENTER FINAL AFT DIAMETER=(CM)"
210 INPUT D2
220 D2=D2/2.54
230 A1=PI*1.2^2/4 ! AREA THROAT
240 DISP "ENTER FUEL TYPE=(HTPB/PMM)"
250 INPUT F1$
260 IF F1$="HTPB" OR F1$="PMM" THEN 290
270 DISP "ONLY FUEL TYPES AVAILABLE ARE <HTPB> OR <PMM>"
280 GOTO 240
290 W3=(W1-W2)/453.6 ! DELTA WEIGHT IN #m
300 ! ENTER Pc DATA
310 SEND 7 ; UNL MLA TALK 23 SCG 5
320 FOR I=1 TO 997 STEP 4
330 ENTER 723 USING "#,K,K,K,K" ; P(I),P(I+1),P(I+2),P(I+3)
340 NEXT I
350 ENTER 7
360 !
370 MAT P=(5)*P
380 FOR I=1 TO 1000
390 P(I)=15.87*P(I)+.22 ! PSIG
400 NEXT I
410 Z0=AMAX(P)
420 J0=AMAXROW @ T0=J0*.06
430 PRINT "MAX Pc=";Z0;" AT TIME=";T0;" SECONDS"
440 FOR I=J0 TO 1000
450 IF P(I)>.2*Z0 THEN 490
460 S2=I
470 PRINT "S2=";S2
480 GOTO 500

```

```

490 NEXT I
500 FOR I=J0 TO 1 STEP -1
510 IF P(I)>.2*Z0 THEN 550
520 S1=I
530 PRINT "S1=";S1
540 GOTO 560
550 NEXT I
560 S3=S2-S1 ! ELEMENTS INCLUDED
570 S4=.06*S1 @ S5=.06*S2
580 S6=.06*S3 ! TIME TBF
590 REDIM P(S3)
600 S7=SUM(P)
610 P1=S7/S3+B9 ! Pc bar(PSIA)
620 REDIM P(1000)
630 GCLEAR @ LOCATE 20,120,20,80 @ FRAME @ SCALE 0,60,0
,100
640 LAXES 5,100,0,0,2,5,5
650 FOR I=2 TO 1000 STEP 2
660 PLOT I*.06,P(I)
670 NEXT I
680 MOVE S4,0 @ PLOT S4,0 @ PLOT S4,P(S1)
690 MOVE S5,0 @ PLOT S5,0 @ PLOT S5,P(S2)
700 MOVE J0*.06,0 @ PLOT J0*.06,0 @ PLOT J0*.06,P(J0)
710 COPY
720 ! FIND M:DOT:AVE AND Tbar:AVE
730 FOR I=1 TO 100
740 IF V(I,3)<S4 THEN 770
750 V4=I
760 GOTO 780
770 NEXT I
780 FOR I=V4 TO 100
790 IF V(I,3)<S5 THEN 820
800 V5=I
810 GOTO 830
820 NEXT I
830 V6=0 @ T=0 @ T3=0
840 FOR I=V4 TO V5
850 V6=V6+V(I,1) ! M:DOT AVE
860 T3=T3+V(I,4) ! T:HOT AIR
870 T=T+V(I,2) ! T:BAR AVE
880 NEXT I
890 V8=V5-V4 ! TIME INT
900 V6=V6/V8 ! M:DOT AVE
910 T3=T3/V8 ! T:HOT:AIR:AVERAGE
920 T=T/V8 ! T:bar AVE
930 PRINT "Pc:bar=";P1;" PSIA"
940 PRINT "Tbf=";S6;" SECONDS"
950 PRINT "m:AVE=";V6
960 PRINT "T:BARave=";T
970 PRINT "T:hot:air=";T3

```

```

980 PRINT
990 V7=W3/S6 ! FUEL FLOW RATE
1000 X1=V7/V6 ! fuel/air ratio
1010 PRINT "f=";X1
1020 IF F1$="HTPB" THEN GOSUB 1130
1030 IF F1$="PMM" THEN GOSUB 1280
1040 GOSUB 1420
1050 GOSUB 1450
1060 T2=(P1*A1*C*F2/(V6+V7))^2 ! Tcexp
1070 N0=(T2-T)/(T1-T) ! EFFICIENCY
1080 PRINT "Tc:THEORY=";T1
1090 PRINT "Tc:EXP = ";T2
1100 PRINT "T:BAR:AVE=";T
1110 PRINT "THERMAL EFFICIENCY =" ;N0
1120 END
1130 ! HTPB SUBROUTINE
1140 F9=.073 ! F:STOICH
1150 D9=.0332 ! DENSITY #m/in^3
1160 X=X1/F9
1170 T1=-933.3+4893*X+203*X^2-899*X^3-205.9*X^6+1.1925*
T+.0001014*T^2-.0000000184*T^3-1.138*T*X
1180 T1=T1+.3864*T*X^2-.0000767*T^2*X
1190 G=1.40162-.27723*X+.1483*X^2-.02448*X^3+.00523*X^6
-.00004994*T+.000000004255*T^2-2.36E-13*T^3
1200 G=G+.000077585*T*X-.000031138*T*X^2-.000000001885*
T^2*X
1210 R=52.966+3.516*X-9.55*X^2+5.71*X^3+.2739*X^6-.0008
08*T+.000000136*T^2-5.99E-11*T^3
1220 R=R+.0010208*T*X-.0001872*T*X^2+.0000002185*X*T^2
1230 PRINT "PHI=";X
1240 PRINT "Tc:th=";T1
1250 PRINT "Rc:th=";R
1260 PRINT "GAMMAC=";G
1270 RETURN
1280 ! PMM SUBROUTINE
1290 F9=.12 ! F:STOICH
1300 D9=.0426 ! DENSITY #m/in^3
1310 X=X1/F9
1320 T1=1642-5902*X+14688*X^2-7478*X^3+4.05*T*X-.18*T-4
.68*T*X^2+1.28*T*X^4-.00003259*T^2*X^2
1330 G=1.34-.0265*X-.193*X^2+.1329*X^3-.000009126*T-.00
004205*T*X+.00007429*T*X^2-.0000272*T*X^4
1340 G=G+.00000000209*T^2*X^2
1350 R=47.1569+X*(27.54+X*(2.9108-X*(41.242-X*(19.545-1
1.567*X^3))))
1360 R=R+.000001*T*(12403-.0032029*T^2)
1370 PRINT "PHI=";X
1380 PRINT "Tc:th=";T1
1390 PRINT "Rc:th=";R
1400 PRINT "GAMMAC=";G

```

```

1410 RETURN
1420 ! F(GAMMA:C)
1430 F2=SQR(G*G1/R*(2/(G+1))^(G+1)/(G-1)))
1440 RETURN
1450 ! D:FINAL:AVERAGE
1460 D8=SQR(4*W3/(PI*D9*L2)+D0^2) ! D:FINAL AVE.
1470 R8=(D8-D0)/(2*S6) ! AVE BURN RATE
1480 D8=2.54*D8 ! IN CM.
1490 R8=2.54*R8 ! IN CM/SEC
1500 PRINT
1510 PRINT "d:final:AVE=";D8
1520 PRINT "AVE:burn RATE=";R8
1530 RETURN

```



```

10 ! HELP
20 ! BERT HANSEN
30 !
40 ! THIS PROGRAM INITIATES THE LIGHT DIFFRACTION EXPER
    IMENT.
50 ! IT ALSO PROVIDES HELP WITH THE DOCUMENTATION.
60 !
70 OPTION BASE 1
80 CLEAR
90 COM Q1$(12),Q2$(12),T1$(20),D1$(12),D2$(12)
100 DISP "ENTER DATE;TIME(MMDDHHMMSS)"
110 INPUT T1$
120 OUTPUT 709 ; "TD"&T1$
130 OUTPUT 709 ; "TD"
140 Q$="DATA" ! TYPICAL NAME
150 CLEAR
160 F=0 ! FLAG RESET
170 CRT IS 1
180 DISP "ENSURE THAT THE FOLLOWING EQUIPMENT IS TURNED
    ON."
190 DISP " 1.ALL HP-IB EQUIP."
200 DISP " 2.VISICORDER"
210 DISP " 3.RETICON ARRAY."
220 DISP " 4.LASER"
230 DISP " 5.BATTERY AND IGNITION CONTROL CIRCUITS."
240 DISP " 6.LOW PASS FILTER"
250 DISP "The following programs are associated with t
    he light diffraction experiment."
260 DISP
270 DISP " PRESS [CONT] WHEN READY."
280 IF F=0 THEN PAUSE
290 DISP " 1.ACQDTA- acquires data from both diode arra
    ys and stores it on the disc."
300 DISP
310 DISP " 2.CMBINE-combines raw data arrays into TWO 1
    024x2 arrays and datafiles."
320 DISP
330 DISP " 3.PLTDTA-plots the raw data from the datafil
    e as VOLTAGE VS. DIODE NUMBER."
340 DISP
350 DISP " PRESS [CONT] WHEN READY."
360 IF F=0 THEN PAUSE
370 DISP " 4.REDUCE-performs the reduction math and plo
    ts NORMALIZED INTENSITY VS. THETA."
380 DISP
390 DISP " 5.REDOC2-plots the ideal curve from disc. Ca
    libration data can also be plotted."
400 DISP
410 DISP " PRESS [CONT] WHEN READY."
420 IF F=0 THEN PAUSE

```

```

430 DISP " 6.REDUC3-Computes D32 from the user specifie
d datafile and calcs. theta bar."
440 DISP
450 DISP " 7.CALIB- If a run is to be a calibration cur
ve this"
460 DISP " program performs a curve fit to get a smooth
curve for comparison."
470 DISP
480 DISP " 8.REDUC4-Plots INTENSITY VS THETA BAR"
490 DISP "using D32 entered by user in format like RED
UC2"
500 IF F=0 THEN PAUSE
510 IF F=2 THEN GOTO 580
520 DISP " DO YOU WANT A HARD COPY OF THE INSTRUCTIONS?
(Y/N)"
530 INPUT A$
540 IF A$="N" THEN GOTO 580
550 F=2 ! FLAG SET
560 CRT IS 2
570 GOTO 180 ! RETURNS TO PRINT
580 CRT IS 1
590 CLEAR
600 CHAIN "ACQDTA"
610 END

```

AD-A125 195

AUTOMATIC CONTROL AND DATA ACQUISITION SYSTEM FOR  
COMBUSTION LABORATORY APPLICATIONS(U) NAVAL  
POSTGRADUATE SCHOOL MONTEREY CA B J HANSEN

OCT 82

F/G 21/2

NL

UNCLASSIFIED

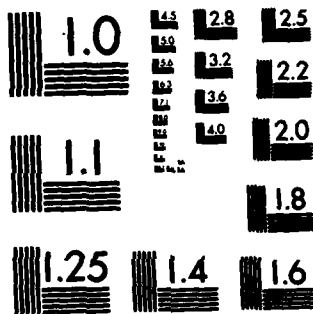
END

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83

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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

```

100 ! ACQDTA
110 ! BERT HANSEN
120 OPTION BASE 1
130 OUTPUT 709 "T0500" ! TIME SIGNAL TO VISICORDER
140 COM Q1$(12),Q2$(12),T1$(20),D1$(12),D2$(12)
150 SHORT A(1032),B(1032)
160 OUTPUT 709 ; "TD"
170 ENTER 709 ; T1$
180 PRINT "DATE:TIME IS ";T1$
190 OUTPUT 709 "AR,D04,0,2,3"
200 OUTPUT 723 ; "CC,2,3,12,13T,WF,3.1,0,3.2,0,3.3,0T,WF
,13.1,0,13.2,0,13.3,0T"
210 CLEAR
220 CLEAR 722
230 DISP "ENTER THE FILENAME OF THE DATA FILES TO BE CR
EATED.(RAW1,RAW2) (MAX 12 CHAR.)"
240 DISP "DATA SHOULD BE STORED ON DRIVE #1 BY TYPING
(:D701) AFTER FILENAME."
250 DISP " BE SURE THE FILES NAMED DO NOT ALREADY EXIST
ON DISC"
260 INPUT D1$,D2$
270 CLEAR
280 M5=1024
290 CREATE D1$,1024,16
300 CREATE D2$,1024,16
310 PRINT " DATA WILL BE STORED ON DISC WITH FILE NAME
AS FOLLOWS."
320 PRINT "NO PARTICLES-",D1$
330 PRINT "PARTICLES-",D2$
340 DISP "ENTER THE THRESHOLD PRESSURE TO TRIGGER DEVIC
ES (PSI)"
350 INPUT S8 ! DESIRED PRESSURE
360 DISP "ENTER TIME DELAY IN SECONDS FROM THRESHOLD PR
ESSURES (SECS.)"
370 INPUT T8
380 T8=(T8-.25)*1000
390 V8=S8/151.5
400 !
410 CLEAR
420 DISP " LASER ON ,IGNITION OFF"
430 D3$=D1$
440 GOSUB 840 ! CALL MULTIPROGRAMMER
450 GOSUB 1180 ! STORE DATA
460 OUTPUT 709 "AC0" ! CONNECT 3456 TO IGNITION FIRING
LINE
470 LOCAL LOCKOUT 7
480 R7=225
490 OUTPUT 722 "HSM002SM2S01L1S0F4R1T3QX1"
500 GOSUB 1260 ! ENTER READING
510 R8=V

```

```

520 IF R8<R7 THEN GOTO 570
530 ! CONTINUITY CHECK
540 DISP "CONTINUITY CHECKS BAD RECHECK BEFORE PROCEEDI
NG, THEN PRESS[CONT]"
550 PAUSE
560 GOTO 490
570 CLEAR
580 DISP "CONTINUITY IS OK"
590 OUTPUT 709 ;"DC4,2" ! NITROGEN ON
600 DISP
610 OUTPUT 709 ;"AC2" ! CONNECT DVM TO FIRE SWITCH
620 DISP " ENSURE VISICORDER IS SET UP TO RUN ON PROPER
SCALE AND LAMP IS ON"
630 OUTPUT 722 "HSM002SW2Z0S01L1FL0.01STIS0F1R1T3Q"
640 DISP "STANDING BY FOR IGNITION"
650 BEEP
660 OUTPUT 722 "X1" @ GOSUB 1260 ! ENTER DATA

670 R9=ABS(V) @ IF R9<10 THEN GOTO 660
680 O0=TIME @ OUTPUT 709 "DC4,0" @ ON TIMER# 1,5000 GOS
UB 1250
690 OUTPUT 709 "AC1" @ CLEAR
700 OUTPUT 722 ;"X1" @ GOSUB 1260 ! ENTER DATA

710 R9=ABS(V) @ IF R9<V0 THEN GOTO 700
720 WAIT T8 @ O1=TIME
730 GOSUB 840 ! MULTIPROGRAMMER
740 WAIT 3000
750 OUTPUT 709 ;"DO4,0"
760 LOCAL 7
770 D3$=D2$
780 GOSUB 1180 ! STORE DATA
790 PRINT "TIME FIRE TO MULTI CALL=";O1-00
800 PRINT "TIME FIRE TO MEM INTR=";O2-00
810 PRINT "DATA STORED ON DISK WITH FILENAMES (";D1$;")
AND (";D2$;")"
820 CHAIN "CMBINE"
830 END
840 ! MULTIPROGRAMMER ROUTINE
850 OUTPUT 723 ;"SF,2,3,1,.001,12T,SF,12,3,1,.001,12T"
860 OUTPUT 723 ;"WF,3.1,0T,WF,3.2,0T,WF,3.3,0T,WF,13.1,
0T,WF,13.2,0T,WF,13.3,0T"
870 OUTPUT 723 ;"WF,3,1031T,WF,13,1031T,MI,2,1032T"
880 OUTPUT 709 ;"DC4,3" ! MARKS THE VISICORDER TRACE

890 OUTPUT 723 ;"AC,3T,WF,4.2,1T,OP,4,16.5T"
900 K=SPOLL(723) ! WAIT FOR MEM INTERRUPT
910 IF K<>64 THEN GOTO 900
920 O2=TIME
930 OUTPUT 709 ;"DO4,3"
940 DISP " DATA TAKEN AND STORED"

```

```

950 SEND 7 ; UNL MLA TALK 23 SCG 12
960 ENTER 7 ; K1
970 DISP "MEMORY BOARD HAS DATA"
980 DISP " SLOT#=";K1
990 OUTPUT 723 ;"DC,3T,WF,4.2,0T"
1000 ENABLE INTR 7;8
1010 SEND 7 ; UNL MLA TALK 23 SCG 5
1020 FOR I=1 TO 1025 STEP 8
1030 ENTER 723 USING "#,K,K,K,K,K,K,K,K" ; A(I),A(I+1),
A(I+2),A(I+3),A(I+4),A(I+5),A(I+6),A(I+7)
1040 NEXT I
1050 ENTER 7
1060 DISP " ARRAY ONE DATA ENTERRED"
1070 OUTPUT 723 ;"HI,12,1032T"
1080 SEND 7 ; UNL MLA TALK 23 SCG 5
1090 FOR I=1 TO 1025 STEP 8
1100 ENTER 723 USING "#,K,K,K,K,K,K,K,K" ; B(I),B(I+1),
B(I+2),B(I+3),B(I+4),B(I+5),B(I+6),B(I+7)
1110 NEXT I
1120 ENTER 7
1130 DISP " ARRAY TWO DATA ENTERRED"
1140 MAT A=-A
1150 MAT B=-B
1160 OUTPUT 723 ;"CC,2,3,12,13T"
1170 RETURN
1180 ! THIS ROUTINE STORES THE RAW DATA ON THE DISK
1190 ASSIGN# 1 TO D3#
1200 FOR I=7 TO 1027 STEP 4
1210 PRINT# 1 ; A(I),A(I+1),A(I+2),A(I+3),B(I),B(I+1),B
(I+2),B(I+3)
1220 NEXT I
1230 ASSIGN# 1 TO *
1240 RETURN
1250 OFF TIMER# 1 @ OUTPUT 709 ;"DO4,0,2" @ RETURN
1260 ! SRQ SERVICE
1270 STATUS 7,1 ; A0
1280 ENTER 722 ; V
1290 ENABLE INTR 7;8 @ RETURN

```

```

10 ! CMbine
20 ! COMBINES RAW DATA FILES INTO A SINGLE DATA FILE
30 OPTION BASE 1
40 COM Q1$(121),Q2$(121),T1$(20),D1$(121),D2$(121)
50 D9$=":D781"
60 CLEAR
70 !
80 SHORT Y(1024,4)
90 D3$=D1$
100 FOR M=1 TO 2
110 ASSIGN# 2 TO D3$
120 FOR I=1 TO 1021 STEP 4
130 READ# 2 ; Y(I,M),Y(I+1,M),Y(I+2,M),Y(I+3,M),Y(I,M+2),
Y(I+1,M+2),Y(I+2,M+2),Y(I+3,M+2)
140 NEXT I
150 ASSIGN# 2 TO *
160 D3$=D2$
170 NEXT M
180 Q3$=D1$
190 FOR M=1 TO 3 STEP 2
200 ASSIGN# 1 TO Q3$
210 FOR N=1 TO 1017 STEP 8
220 A=Y(N,M) @ B=Y(N+1,M) @ C=Y(N+2,M) @ D=Y(N+3,M)
230 E=Y(N+4,M) @ F=Y(N+5,M) @ G=Y(N+6,M) @ H=Y(N+7,M)
240 R=Y(N,M+1) @ S=Y(N+1,M+1) @ T=Y(N+2,M+1) @ U=Y(N+3,
M+1) @ V=Y(N+4,M+1)
250 W=Y(N+5,M+1) @ X=Y(N+6,M+1) @ Z=Y(N+7,M+1)
260 PRINT# 1 ; A,B,C,D,E,F,G,H,R,S,T,U,V,W,X,Z
270 NEXT N
280 ASSIGN# 1 TO *
290 Q3$=D2$
300 NEXT M
310 DISP " DATA STORED ON DISK ON FILE (":D1$;" ) AND ( "
":D2$;" )"
320 PRINT
330 PRINT "DATA FILES HAVE BEEN REARRANGED A FOLLOWS:"
340 PRINT "PHOTO ARRAY #1 IS ":D1$
350 PRINT "PHOTO ARRAY #2 IS ":D2$
360 CHAIN "PLTDTA"
370 END

```



```

10 ! PLTDTA REVISION 1
20 !
30 ! PLOTTING RAW DATA FROM ARRAY
40 !
50 ! BERT HANSEN
60 CLEAR
70 OPTION BASE 1
80 COM Q1$(12),Q2$(12),T1$(20),D1$(12),D2$(12)
90 OUTPUT 709 ; "TD"
100 ENTER 709 ; T1$
110 DISP " ENSURE PLOTTER IS READY FOR PLOTTING WITH CL
EAN PAPER AND DESIRED PEN."
120 DISP "PRESS (CONT) WHEN READY!"
130 BEEP
140 PAUSE
150 DISP " ENTER THE FILE NAME OF THE DATA TO BE PLOTTE
D.( ";D1$;" OR ";D2$;" )"
160 DISP "DRIVE MUST BE SPECIFIED AS (NAME:D701)"
170 INPUT Q3$
180 DISP "ENTER DESIRED PLOTTING INTERVAL OF DIODE ARRA
Y (2,4,6)"
190 INPUT J
200 CLEAR
210 DISP "READING DATA FROM DATA      FILE ON DISC DRIVE
"
220 PLOTTER IS 705
230 SHORT Y(1024,2),X(1024)
240 M5=1024
250 REDIM X(M5),Y(M5,2)
260 P1$="VOLTAGE"
270 P2$="DIODE NUMBER"
280 P3$="VOLTAGE VS. DIODE"
290 P4$="PLTDTA RESULTS"
300 !
310 ASSIGN# 1 TO Q3$
320 FOR I=1 TO M5-7 STEP 8
330 READ# 1 ; A,B,C,D,E,F,G,H,R,S,T,U,V,W,X,Z
340 Y(I,1)=A @ Y(I+1,1)=B @ Y(I+2,1)=C @ Y(I+3,1)=D @ Y
(I+4,1)=E @ Y(I+5,1)=F
350 Y(I+6,1)=G @ Y(I+7,1)=H
360 Y(I,2)=R @ Y(I+1,2)=S @ Y(I+2,2)=T @ Y(I+3,2)=U @ Y
(I+4,2)=V @ Y(I+5,2)=W
370 Y(I+6,2)=X @ Y(I+7,2)=Z
380 NEXT I
390 M7=MAXAB(Y)
400 DISP "DATA INPUT COMPLETE"
410 LIMIT 0,250,0,180
420 FRAME
430 LOCATE 20,120,20,80
440 FRAME

```

```

450 SCALE 0,MS,-.1,M7+.1
460 CSIZE 3,.5,0
470 DEG
480 LDIR 0
490 FXD 0,2
500 LAXES MS/20,.02,0,0,2,5,5
510 MOVE .65*MS,.93*(M7+.1)
520 LABEL P4$
530 MOVE .65*MS,.84*(M7+.1)
540 LABEL P3$
550 LABEL T1$
560 MOVE MS/2,-.05
570 LABEL P2$
580 LDIR 90
590 MOVE -(.1*MS),.5*M7
600 LABEL P1$
610 LDIR 0
620 M=1
630 GOSUB 760 ! PLOT FIRST ARRAY
640 DISP " FIRST ARRAY PLOTTED!"
650 M=2
660 GOSUB 760 ! PLOT SECOND ARRA492 MOVE .65*MS,.74*(M7
+.1)
670 DISP " SECOND ARRAY PLOTTED!"
680 DISP " PLOT COMPLETE!"
690 DISP "DO YOU WISH TO PLOT THE OTHER PHOTO ARRAY FIL
E? (Y/N)"
700 INPUT N$
710 IF N$="Y" THEN GOTO 110
720 CLEAR
730 DISP "LOAD AND RUN (REDUCE) TO PROCEED WITH DATA RE
DUCTIONS."
750 END
760 ! PLOT DATA
770 X(1)=1
780 MOVE X(1),Y(1,1)
790 FOR I=1 TO MS STEP J
800 X(I)=I
810 PLOT X(I),Y(I,M)
820 NEXT I
830 PENUP
840 RETURN

```

```

10 ! REDUCE
20 CLEAR 7
30 DISP "REDUCE LOADED"
40 !
50 ! BERT HANSEN
60 ! THIS PROGRAM REDUCES THE ARRAY DATA
70 OPTION BASE 1
80 DIM A(2,2),B(2),Y1(2)
90 COM Q3$(12),Q2$(12),T1$(20),D1$(12),D2$(12),M
100 OUTPUT 709 ; "TD"
110 ENTER 709 ; T1$
120 CLEAR
130 DISP "DATA REDUCTION BEGINS"
140 DISP " ENTER THE INDEX OF REFRACTION=?(AIR M=1.0, W
ATER M=1.35)"
150 INPUT M
160 DISP "INSTALL PAPER AND PEN ON PLOTTER TO PLOT I()
VS "
170 DISP "PRESS[CONT] WHEN DONE"
180 PAUSE
190 DISP "ENTER THE FILE NAME OF DATA TO BE REDUCED."
200 DISP "INCLUDE THE DISC LOCATION ON FILENAME ( NAME:
D701)"
210 INPUT A$
220 D9$=":D701"
230 L=.000000488 ! WAVELENGTH IN METERS
240 SHORT T1(1024),I1(1024),I2(1024)
250 M5=1024 ! CURRENT NUMBER OF ACTUAL READINGS
260 D8=1.5365 ! MMETERS
270 F8=526 ! MMETERS
280 D1=.025 ! MMETERS
285 GCLEAR
290 PLOTTER IS 705
300 LIMIT 0,250,0,180
310 LOCATE 20,120,20,80
320 FRAME
330 SCALE 0,.04,-.1,1
340 CSIZE 3,.5,0
350 DEG
360 LDIR 0
370 FXD 3,1
380 LAXES .002,.1,0,0,2,2,5
390 DISP "DO YOU WANT TO PLOT A COMPARISON CURVE ( UNIC
UR)? (Y/N)"
400 INPUT N$
410 IF N$="Y" THEN GOSUB 1140
420 ASSIGN# 1 TO A$
430 FOR I=1 TO M5-7 STEP 8
440 READ# 1 ; A,B,C,D,E,F,G,H,R,S,T,U,V,W,X,Z
450 I2(I)=A @ I2(I+1)=B @ I2(I+2)=C @ I2(I+3)=D @ I2(I+

```

```

4)=E @ I2(I+5)=F @ I2(I+6)=G @ I2(I+7)=H
460 I1(I)=R @ I1(I+1)=S @ I1(I+2)=T @ I1(I+3)=U @ I1(I+
4)=V @ I1(I+5)=W @ I1(I+6)=X @ I1(I+7)=Z
470 NEXT I
480 MAT I1=I1-I2
490 Z9=AMAX(I1)
500 Z0=AMAXROW
510 PRINT "MAXIMUM OUTPUT AT DIODE#=";Z0
520 DISP "ENTER THE INCREMENT AFTER PEAK (J=#START,K=#
STOP FIT)"
530 INPUT J,K
540 N0=K-J
550 X1=0 @ X2=0 @ X3=0 @ Y1=0 @ Y2=0
560 FOR N=J TO K
570 T1(N)=N+61.46
580 X1=X1+T1(N)
590 X2=X2+T1(N)^2
600 X3=X3+T1(N)*I1(N)
610 Y1=Y1+I1(N)
620 Y2=Y2+I1(N)^2
630 NEXT N
640 A(1,1)=N0
650 A(1,2)=X1
660 A(2,1)=X1
670 A(2,2)=X2
680 Y1(1)=Y1
690 Y1(2)=X3
700 MAT B=SYS(A,Y1)
710 PRINT "DELTA=";B(1)
720 PRINT "SLOPE=";B(2)
730 A3=B(1)
740 R2=(N0*X3-X1*Y1)^2/((N0*X2-X1^2)*(N0*Y2-Y1^2)) ! CO
RRELATION
750 PRINT
760 PRINT "CORRELATION R^2=";R2
770 MAT I1=(1/A3)*I1
780 ! I1 ARRAY IS THE FINAL PLOTTING NORMALIZED ARRAY
790 ! NOW PLOT I1 VS. T1
800 FOR I=1 TO M5
810 T1(I)=(I*.025+D0)/(F8*M) ! THETA
820 PLOT T1(I),I1(I)
830 NEXT I
840 PENUP
850 MOVE 0,0
860 MOVE .02,-.3
870 LABEL "THETA (RADIAN)"
880 MOVE -.004,.2 @ DEG @ LDIR 90
890 LABEL "NORMALIZED INTENSITY"
900 LDIR 0 @ MOVE .015,.8
910 LABEL "INTENSITY VS. THETA"

```

```

920 MOVE .015,.9
930 LABEL "REDUCE RESULTS"
940 MOVE .015,.7
950 LABEL T1$
960 Q5$="REDUC3"
970 DISP " IS THIS A CALIBRATION RUN? (Y/N)"
980 INPUT N$
990 IF N$="N" THEN GOTO 1010
1000 Q5$="CALIB"
1010 DISP "ENTER THE NAME OF THE DATA FILE TO STORE THE
DATA (INTENSITY VS.THETA)"
1020 DISP "INCLUDE THE DISC LOCATION ON FILENAME ( NAME
:D701)"
1030 INPUT Q3$
1040 CREATE Q3$,1024,16
1050 PRINT "INTENSITY VS.THETA STORED IN FILE=";Q3$
1060 ASSIGN# 2 TO Q3$
1070 FOR I=1 TO M5
1080 PRINT# 2 ; T1(I),I1(I)
1090 NEXT I
1100 ASSIGN# 2 TO *
1110 DISP "DATA STORED ON DISK IN FILE -- ";Q3$
1120 CHAIN Q5$
1130 END
1140 ! COMPARE WITH UNICUR
1150 ASSIGN# 2 TO "UNICUR"
1160 FOR I=1 TO 100 STEP 2
1170 READ# 2 ; T1(I),I1(I),T1(I+1),I1(I+1)
1180 NEXT I
1190 DISP "ENTER EXPECTED VALUE OF Dbar (23.98E-6)ETC."

1200 INPUT D
1210 FOR I=1 TO 99
1220 T1(I)=T1(I)*L/(PI*D)
1230 PLOT T1(I),I1(I)
1240 NEXT I
1250 PENUP
1260 RETURN

```

```

10 ! CALIB
20 OPTION BASE 1
30 COM Q3$(12),Q2$(12),T1$(20),D1$(12),D2$(12),M
40 D9$=";D701"
50 ! CALIBRATION PROCEDURE
60 ! BERT HANSEN
70 CLEAR
80 GCLEAR
90 DISP "ARE YOU RUNNING CALIB SEPARATELY? (Y/N)"
100 INPUT N$
110 IF N$="N" THEN 160
120 DISP "ENTER DATAFILE NAME AND DRIVE ADDRESS"
130 INPUT Q3$
140 DISP "ENTER INDEX OF REFRACTION (AIR=1.0 ,WATER=1.3
5)"
150 INPUT M
160 DISP "ENTER THE ADDRESS OF PLOTTER. (CRT=1, 7225B=7
05)"
170 INPUT P
180 PLOTTER IS P
190 IF P=705 THEN LIMIT 0,250,0,180
200 LOCATE 20,120,20,80
210 FRAME
220 SCALE 0,10,-.1,1
230 LAXES .5,.2,0,0,2,5,5
240 !
250 DIM A(11,11),B(11),W(20),Y1(11),Y2(11)
260 SHORT X(1024),Y(1024)
270 MAT A=ZER
280 MAT B=ZER
290 MAT Y1=ZER
300 MAT W=ZER
310 M5=1024
320 DISP " INDEX OF REFRACTION IS ";M
330 DISP "USING ( ";Q3$;" )"
340 DISP "A POLYNOMIAL REGRESSION ROUTINE OF (J)TH ORDE
R WILL BE PERFORMED. "
350 DISP "ENTER ORDER OF POLYNOMIAL( REASONABLE). "
360 INPUT J1
370 ASSIGN# 1 TO Q3$
380 FOR I=1 TO M5 STEP 2
390 READ# 1 ; X(I),Y(I),X(I+1),Y(I+1)
400 NEXT I
410 DISP "ENTER Dbar TO USE IN DATA REDUCTION (e.g. 23
.98E-6)"
420 INPUT D3
430 L=.000000488
440 F=326 ! FOCAL LENGTH
450 K6=D3*PI/L
460 OR I=1 TO M5

```

```

470 X(I)=X(I)*K6
480 PLOT X(I),Y(I)
490 NEXT I
500 ! I VS. THETA BAR
510 PENUP
520 DISP "ENTER THE MINIMUM THETA BAR OF INTEREST."
530 INPUT J
540 J=M*J/(236*D3)-61.46
550 K=1.5365
560 DISP "ENTER THE MAXIMUM THETA BAR OF INTEREST .(b4
r=3.5)"
570 INPUT M1
580 M1=(M1*L*F*M/(PI*D3)-K)/.02533
590 PRINT "MIN DIODE =" ; J
600 PRINT "MAX DIODE =" ; M1
610 J2=J1+1
620 FOR I=1 TO 2*J1
630 !
640 S0=0
650 FOR M=J TO M1
660 !
670 S0=X(M)^I+S0
680 NEXT M
690 W(I)=S0
700 NEXT I
710 !
720 FOR I=1 TO J2
730 S0=0
740 FOR N=J TO M1
750 S0=S0+Y(N)*X(N)^(I-1)
760 NEXT N
770 Y1(I)=S0
780 NEXT I
790 N0=M1-J ! # OF DATA PAIRS
800 !
810 REDIM A(J2,J2),B(J2),W(2*J1),Y1(J2),Y2(J2)
820 A(1,1)=N0
830 FOR I=2 TO J2 ! FIRST ROW
840 A(1,I)=W(I-1)
850 NEXT I
860 !
870 FOR I=2 TO J2 ! FIRST COLUMN
880 A(I,1)=W(I-1)
890 NEXT I
900 !
910 M=0
920 FOR I=2 TO J2 ! CORE 10*10
930 FOR K=2 TO J2
940 A(I,K)=W(K+M)
950 NEXT K
960 M=1+1

```

```

970 NEXT I
980 GOSUB 1300 ! CORRELATION
990 !
1000 MAT B=SYS(A,Y1)
1010 PRINT
1020 PRINT "POLYNOMIAL COEFFICIENTS=: "
1030 PRINT
1040 MAT PRINT B
1050 !
1060 ! COMPUTE THE CALIBRATION CURVE
1070 S=.1
1080 FOR I=1 TO 100
1090 X(I)=I*S
1100 S0=0
1110 FOR N=1 TO J2
1120 S0=S0+B(N)*X(I)^(N-1)
1130 NEXT N
1140 Y(I)=S0
1150 PLOT X(I),Y(I)
1160 NEXT I
1170 DISP " COMPLETE !"
1180 DISP "ENTER THE DESIRED FILE NAME TO STORE DATA."
1190 INPUT Q3$
1200 CREATE Q3$,100,16
1210 ASSIGN# 2 TO Q3$
1220 ! STORE SMOOTH CAL CURVE ON DISC.
1230 FOR I=1 TO 100 STEP 2
1240 PRINT# 2 ; X(I),Y(I),X(I+1),Y(I+1)
1250 NEXT I
1260 DISP "DATA STORED ON DISC"
1270 ASSIGN# 2 TO *
1280 CHAIN "REDUC2"
1290 END
1300 ! COMPUTE CORRELATION FACTOR
1310 DISP " CORRELATION "
1320 SHORT X4(1024),Y4(1024)
1330 MAT X4=ZER
1340 MAT Y4=ZER
1350 MAT X4=X(J:M1)
1360 MAT Y4=Y(J:M1)
1370 C1=DOT(X4,X4)
1380 C2=DOT(Y4,Y4)

```



```
1390 C3=DOT(X4,Y4)
1400 C4=C1^2
1410 C5=C2^2
1420 C6=SUM(X4)
1430 C7=SUM(Y4)
1440 N2=N0*C3-C6*C7
1450 D2=SQR((N0*C1-C6^2)*(N0*C2-C7^2))
1460 R=N2/D2 ! CORRELATION FACTOR
1470 R2=R^2
1480 PRINT " CORRELATION FACTOR"
1490 PRINT "R^2=";R2
1500 RETURN
```

```

10 ! REDUC2
20 !
30 ! BERT HANSEN
40 ! THIS PROGRAM WILL RETREIVE THE UNIVERSAL CURVE DA
TA FROM THE DISC.
50 ! IT WILL THEN PLOT THE CURVE AND THEN RETREIVE AND
PLOT THE CALIBRATION CURVES.
60 !
70 CLEAR
80 OPTION BASE 1
90 COM Q3$(12),Q2$(12),T1$(20),D1$(12),D2$(12),M
100 D9$=":D701"
110 L=.000000488
120 F=526
130 K1=1.5365
140 PLOTTER IS 705
150 CSIZE 3,.4,0
160 OUTPUT 709;"TD"
170 ENTER 709;T1$
180 SHORT X(100),Y(100)
190 SHORT T(1024),I(1024)
200 P4$="THETA BAR"
210 P5$="INTENSITY"
220 DIM P3$(26)
230 P3$="INTENSITY VS. THETA BAR"
240 LIMIT 0,250,0,180
260 LOCATE 20,120,20,80
270 FRAME
280 SCALE 0,10,0,3
290 LINETYPE 1
300 E=1
310 E3=3
320 E1$="A,.3D" @ E2$=".3D,A"
330 Y=1 @ Y2=10
340 GOSUB 1230 ! LABEL
350 GOSUB 1300 ! LOG SCALE
360 E1$="A,.2D" @ E2$=".2D,A"
370 E=10*E
380 Y=20 @ Y2=100
390 GOSUB 1300
400 E1$="A,D.D" @ E2$="D.D,A"
410 Y=200 @ Y2=1000
420 E=10*E
430 GOSUB 1300
440 DEG
450 LDIR -91
460 FOR X=0 TO 10
470 ! YAXIS X
480 MOVE X,-.1
490 LABEL USING "DD";X

```

```

500 NEXT X
510 LDIR 0
520 DISP "SCALE COMPLETE"
530 SCALE 0,10,0,1
540 CSIZE 4,.5,0
550 FXD 1,2
560 MOVE 5,-.15
570 LABEL P4$
580 DEG
590 LDIR 90
600 MOVE -1,.5
610 LABEL P5$
620 LDIR 0
630 MOVE 7,.85
640 ! LABEL P3$
650 MOVE 7,.95
660 ! LABEL "REDUC2 RESULTS"
670 MOVE 7,.75
680 ! LABEL T1$
690 Q5$="UNICUR"
700 DISP " LABELING COMPLETE"
710 DISP "CHANGE PENS AND [CONT]"
720 PAUSE
730 SCALE 0,10,-3,0
740 M5=1024
750 ASSIGN# 1 TO Q5$
760 FOR I=1 TO 99
770 READ# 1 ; X(I),Y(I)
780 PLOT X(I),LGT(Y(I))
790 NEXT I
800 PENUP
810 ASSIGN# 1 TO *
820 DISP " DO YOU WANT TO PLOT A CALIBRATION CURVE? (Y/
N)"
830 INPUT N$
840 IF N$="N" THEN GOSUB 930
850 DISP " ENTER THE FILE NAME OF THE CALIBRATION CURVE
TO BE PLOTTED. (CAL1,ETC)"
860 DISP " INCLUDE THE DISC DRIVE WHERE CAL FILE IS STO
RED--E.G. -NAME:D701"
870 INPUT Q3$
880 ! DISP "ENTER THE NUMBER OF DATA POINTS IN THE FILE
.(100,1024,ETC)"
890 ! INPUT M2 ! CAL FILES HAVE 100 ELEMENTS

900 M2=100
910 GOSUB 980 ! CALC THETA BAR AND PLOT !
920 GOTO 820
930 LINETYPE 1
940 CLEAR

```

```

950 DISP "PLOTS COMPLETE !"
960 DISP "LOAD REDUC3 TO COMPUTE D32 FROM A DATA SET."
970 END
980 ! READ AND PLOT CAL
990 DISP "ENTER THE INDEX OF REFRACTION USED FOR THE CA
L RUN. (AIR=1.0, WATER=1.35)"
1000 INPUT M
1010 DISP "ENTER THE Dbar USED TO COMPUTE THETA BAR."
1020 INPUT D
1030 DISP "ENTER THE DIODE NUMBERS FOR THE REGION OF IN
TEREST. (P1,P2) TYPICALLY (50,400)"
1040 INPUT P1,P2
1050 H9=D*PI#.025/(L*F*M)
1060 P1=H9*(61.46+P1)
1070 P2=H9*(61.46+P2)
1080 PRINT "LOWER LIMIT OF THETA BAR=";P1
1090 PRINT
1100 PRINT "UPPER LIMIT OF THETA BAR=";P2
1110 ASSIGN# 1 TO Q3#
1120 FOR I=1 TO M2
1130 READ# 1 ; T(I),I(I)
1140 NEXT I
1150 MOVE T(1),I(1)
1160 FOR I=1 TO 100
1170 IF T(I)<P1 THEN 1200
1180 IF T(I)>P2 THEN 1200
1190 IF I(I)>0 THEN PLOT T(I),LGT(I(I))
1200 NEXT I
1210 PENUP
1220 RETURN
1230 ! LABEL
1240 Y3=Y/1000
1250 MOVE 10.1,LGT(Y) @ LONG 2
1260 LABEL USING E1# ; "--",Y3
1270 MOVE -.1,LGT(Y) @ LONG 8
1280 LABEL USING E2# ; Y3,"-"
1290 RETURN
1300 FOR Y=Y TO Y2 STEP E
1310 E2=LGT(Y)
1320 ! XAXIS LGT(Y)
1330 IF RMD(Y,10*E)#0 THEN 1350
1340 GOSUB 1230 ! LABEL
1350 NEXT Y
1360 RETURN

```

```

10 | REDUC3
40 |
50 | THIS ROUTINE COMPUTE THE VALUE OF D32 FOR THE DA
TA IN THE FILE "Q#"
60 | BERT HANSEN 13 JULY 82
70 |
80 OPTION BASE 1
90 M5=1024
100 COM Q3$(12),Q2$(12),T1$(20),D1$(12),D2$(12),M
110 CLEAR
120 D9$=":D701"
130 SHORT R(20),X1(100),Y1(100)
140 SHORT X(1024),Y(1024),D3(20),T3(20),T(1024)
150 DISP "ENTER THE FILENAME OF THE DATA TO BE REDUCED
(DATA1:D701,ETC)"
160 INPUT Q3$
170 ASSIGN# 2 TO Q3$
180 FOR I=1 TO M5-3 STEP 4
190 READ# 2 ; X(I),Y(I),X(I+1),Y(I+1),X(I+2),Y(I+2),X(I
+3),Y(I+3)
200 NEXT I
210 | FOR I=1 TO 1024
220 | X(I)=X(I)/198.54
230 | NEXT I
240 | THETA AND INTENSITY ENTERED
250 L=.000000488
260 K1=L/PI
270 DISP "ENTER THE NAME OF THE DATA FILE OF THE REFERE
NCE ARRAY.(UNICUR,CAL1,CAL2,CAL3)"
280 INPUT Q1$
290 M4=100
300 ASSIGN# 1 TO Q1$
310 FOR I=1 TO M4-1 STEP 2
320 READ# 1 ; X1(I),Y1(I),X1(I+1),Y1(I+1)
330 NEXT I
340 DATA .5,.3,.2,.1,.09,.08,.07,.06,.05,.04,.03,.02,.0
1,.008,.005
350 FOR N=1 TO 15
360 READ R(N) | REF INTENSITIES
370 NEXT N
380 DISP "ENTER THE NUMBER OF DIODES TO BE OMITTED CLO
SE TO THE CENTERLINE."
390 INPUT J
400 | D32 CALCULATION
410 J1=2
420 FOR D=1 TO 15
430 R1=R(D) | REF INTENSITY
440 O1=AMIN(Y) | SKALLEST INTENSITY
450 IF R1<O1 THEN GOTO 1250
460 FOR I=J1 TO 100

```

```

470 IF Y1(I)>R1 THEN GOTO 610
480 IF Y1(I)=Y1(I-1) THEN GOTO 600
490 ! FIND THETA BAR
500 H2=Y1(I-1)-Y1(I)
510 K2=X1(I)-X1(I-1)
520 H3=Y1(I-1)-R1
530 K3=K2*(H3/H2)
540 T3(D)=X1(I-1)+K3 ! THETA BAR
550 PRINT "I=";I;Y1(I);R1;D
560 PRINT "I=";I;T3(D);X1(I-1)+K3
570 PRINT
580 J1=I
590 GOTO 620
600 PRINT " ZERO OR POS SLOPE"
610 NEXT I
620 ! FIND THE INTENSITY CORRESPONDING TO DESIRED INT
    ENSITY
630 M9=1000
640 L9=1
650 FOR I=J TO M9
660 IF Y(I)>0 THEN 690
670 PRINT "INTENSITY VECTOR GOING NEGATIVE AT I=";I
680 PRINT "INCREASING J=J+5" @ J=J+5 @ GOTO 630
690 Z=0
700 FOR M=I-5 TO I+5
710 Z=Z+Y(M)
720 NEXT M
730 Z=.1*Z
740 IF Z>R1 THEN GOTO 790
750 ! Z IS LESS THAN R1
760 J=I ! STARTING POS FOR NEXT SEARCH

770 DISP " I FOUND IT"
780 GOTO 810
790 L9=Z ! LAST AVERAGE
800 NEXT I
810 ! FIND THETA
820 K7=X(J)-X(J-1)
830 H7=L9-Z
840 H6=L9-R1
850 K6=K7*(H6/H7)
860 T4=X(J-1)+K6 ! THETA
870 ! COMPUTE D32
880 D3(D)=K1*T3(D)/T4 ! D32
890 PRINT
900 PRINT "FOR INTENSITY=";R(D)
910 PRINT "THETA=";T4;" RADIANS"
920 PRINT "THETA BAR=";T3(D)
930 PRINT "D32=";D3(D)*1000000;" MICRONS"
940 NEXT D
950 D5=0

```

```

960 FOR I1=1 TO D
970 D5=D5+D3(I1)
980 NEXT I1
990 D5=D5/D*1000000
1000 PRINT "D32 AVERAGE=";D5;" MICRONS "
1010 PRINT
1020 DISP "DO YOU WANT TO COMPARE DATA TO ANOTHER REFER
ENCE FILE? (Y/N)"
1030 INPUT N$
1040 IF N$="N" THEN 1080
1050 DISP "ENTER THE FILENAME OF THE REF. DATAFILE (CAL
1A,ETC)"
1060 INPUT Q1$
1070 GOTO 290
1080 DISP "DO YOU WANT TO REDUCE ANOTHER DATAFILE? (Y/N
)"
1090 INPUT N$
1100 IF N$="N" THEN 1180
1110 DISP "ENTER THE FILENAME OF THE DATAFILE TO BE RE
DUCED. (DATA1,ETC)"
1120 INPUT Q$
1130 ASSIGN# 1 TO Q$
1140 FOR I=1 TO 1021 STEP 4
1150 READ# 1 ; X(I),Y(I),X(I+1),Y(I+1),X(I+2),Y(I+2),X(
I+3),Y(I+3)
1160 NEXT I
1170 GOTO 400 ! REPEAT D32 CALCULATIONS
1180 DISP "REDUCTIONS COMPLETED"
1190 DISP "WANT TO DO ANOTHER RUN?"
1200 INPUT N$
1210 IF N$="N" THEN 1230
1220 GOTO 10
1230 CHAIN "REDUC4"
1240 END
1250 ! REF INTENSITY IS LESS THEN SMALLEST INTENSITY
1260 ! DON'T SEARCH JUST COMPUTE D32 AVERAGE TO THIS PO
INT
1270 D5=0
1280 FOR I1=1 TO D-1
1290 D5=D5+D3(I1)
1300 NEXT I1
1310 D5=D5/(D-1) ! D32 AVERAGE
1320 GOTO 1000

```

```

10 ! REDUC4
20 !
30 ! BERT HANSEN
40 ! THIS PROGRAM WILL RETREIVE THE UNIVERSAL CURVE DA
   TA FROM THE DISC.
50 ! IT WILL THEN PLOT THE UNIVERSAL CURVE.

60 ! THE USER MAY THEN PLOT INTENSITY VERSUS THETA BAR
   WITH D32 ENTERED FROM KEYBOARD.
70 !
80 CLEAR
90 GCLEAR
100 OPTION BASE 1
110 COM Q3$(12),Q2$(12),T1$(20),D1$(12),D2$(12),M
120 D9$=":D781"
130 L=.000000488
140 F=526
150 K1=1.5365
160 DISP "ENTER THE PLOTTER ADDRESS (CRT=1, 7225B=705)"

170 INPUT P
180 PLOTTER IS P
190 IF P=705 THEN LIMIT 0,250,0,180
200 CSIZE 3,.4,0
210 OUTPUT 709;"TD"
220 ENTER 709;T1$
230 SHORT X(100),Y(100)
240 SHORT T(1024),I(1024)
250 P4$="THETA BAR"
260 P5$="INTENSITY"
270 DIM P3$(26)
280 P3$="INTENSITY VS. THETA BAR"
290 FRAME
300 LOCATE 20,120,20,80
310 FRAME
320 SCALE 0,10,0,3
330 LINETYPE 1
340 E=1
350 E3=1
360 E1$="A,.3D" @ E2$=".3D,A"
370 Y=1 @ Y2=10
380 GOSUB 1260 ! LABEL
390 GOSUB 1330 ! LOG SCALE
400 E1$="A,.2D" @ E2$=".2D,A"
410 E=10#E
420 Y=20 @ Y2=100
430 GOSUB 1330
440 E1$="A,D.D" @ E2$="D.D,A"
450 Y=200 @ Y2=1000
460 E=10#E

```



```

470 GOSUB 1330
480 DEG
490 LDIR -90
500 FOR X=0 TO 10
510 YAXIS X
520 MOVE X,-.1
530 LABEL USING "DD" ; X
540 NEXT X
550 LDIR 0
560 DISP "SCALE COMPLETE"
570 SCALE 0,10,0,1
580 CSIZE 4,.5,0
590 FXD 1,2
600 MOVE 5,-.15
610 LABEL P4$
620 DEG
630 LDIR 90
640 MOVE -1,.5
650 LABEL P5$
660 LDIR 0
670 MOVE 7,.85
680 LABEL P3$
690 MOVE 7,.95
700 LABEL "REDUC4 RESULTS"
710 MOVE 7,.75
720 LABEL T1$
730 Q5$="UNICUR"
740 DISP " LABELING COMPLETE"
750 DISP "CHANGE PENS AND [CONT]"
760 PAUSE
770 SCALE 0,10,-3,0
780 M5=1024
790 ASSIGN# 1 TO Q5$
800 FOR I=1 TO 99
810 READ# 1 ; X(I),Y(I)
820 PLOT X(I),LGT(Y(I))
830 NEXT I
840 PENUP
850 ASSIGN# 1 TO *
860 DISP " DO YOU WANT TO PLOT A DATA FILE  CURVE? (Y/
N)"
870 INPUT N$
880 IF N$="N" THEN GOSUB 970
890 DISP " ENTER THE FILE NAME OF THE DATA FILE  TO BE
PLOTTED. (NAME;D701)"
900 DISP " INCLUDE THE DISC DRIVE WHERE CAL FILE IS STO
RED--E.G. -NAME:D701"
910 INPUT Q3$
920 M2=1024
930 GOSUB 1010 ! CALC THETA BAR AND PLOT !

```

```

940 IF P=705 THEN 970
950 GRAPH
960 COPY
970 LINETYPE 1
980 CLEAR
990 DISP "PLOTS COMPLETE !"
1000 END
1010 ! READ AND PLOT CAL
1020 DISP "ENTER THE INDEX OF REFRACTION USED FOR THE C
AL RUN. (AIR=1.0, WATER=1.35)"
1030 INPUT M
1040 DISP "ENTER THE D32 TO BE USED IN COMPUTING THETA
BAR."
1050 INPUT D
1060 DISP "ENTER THE DIODE NUMBERS FOR THE REGION OF IN
TEREST. (P1,P2) TYPICALLY (50,400)"
1070 INPUT P1,P2
1080 H9=D*PI*.025/(L*F*M)
1090 P3=H9*(61.46+P1)
1100 P4=H9*(61.46+P2)
1110 K6=D*PI/L
1120 PRINT "LOWER LIMIT OF THETA BAR=";P3
1130 PRINT
1140 PRINT "UPPER LIMIT OF THETA BAR=";P4
1150 ASSIGN# 1 TO Q3#
1160 FOR I=1 TO M2 STEP 4
1170 READ# 1 ; T(I),I(I),T(I+1),I(I+1),T(I+2),I(I+2),T(
I+3),I(I+3)
1180 NEXT I
1190 MOVE T(1),I(1)
1200 FOR I=P1 TO P2
1210 T(I)=K6*T(I)
1220 IF I(I)>0 THEN PLOT T(I),LGT(I(I))
1230 NEXT I
1240 PENUP
1250 RETURN
1260 ! LABEL
1270 Y3=Y/1000
1280 MOVE 10.1,LGT(Y) @ LORG 2
1290 LABEL USING E1# ; "--",Y3
1300 MOVE -.1,LGT(Y) @ LORG 8
1310 LABEL USING E2# ; Y3,"--"
1320 RETURN
1330 FOR Y=Y TO Y2 STEP E
1340 E2=LGT(Y)
1350 XAXIS LGT(Y)
1360 IF RND(Y,10*E)>0 THEN 1380
1370 GOSUB 1260 ! LABEL
1380 NEXT Y
1390 RETURN

```

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